RESPONSE TO USEPA REGION III

USEPA comments on the *Draft RCRA Facility Investigation Report for Solid Waste Management Units 17, 31, 48 and 54 Radford Army Ammunition Plant, Radford, Virginia*, Parsons Engineering Science, Inc., January 1996.

Part I. Response to Draft Comments on RAAP Plan for Establishing Background Soil Concentrations and for Evaluating SWMU Data Against Background, by James R. Brown, U.S. EPA, Office of Solid Waste (5303W). These comments were responded to on June 18, 1996 in a conference call involving Jim Brown (U.S. EPA), Mary Beck (U.S. EPA), Rob Davie (U.S. AEC), John Segna (Parsons ES), and Tim Schmitt (Parsons ES).

Comment 2a: **Arsenic Soil C Shapiro-Wilk test--The wrong coefficients are used. The sample size is 8, so the following coefficients ($a_{(n-i+1)}$) should be used: 0.6052, 0.3164, 0.1743, 0.0561.**

Response: Concur. The wrong coefficients were used for the SWMU 17a and SWMU 17bcd arsenic soil horizon C Shapiro-Wilk tests. The analysis was performed again using the corrects coefficients. However, the results of the test did not change.

Comment 2b: **For all Shapiro-Wilk test results, passing the test at the 1% significance level would suffice (Parsons Engineering used 5%). This allows more of the data sets to pass the test on the original scale, and therefore obviates the need for data transformations in many cases.**

Response: Parsons ES used the more conservative 5% significance level and it does not appear useful to change the significance level of the Shapiro Wilk test now. Parsons ES believes that the transformed data more accurately represents the natural distribution of metals in soil, which are typically assumed to be lognormally distributed. Following a meeting with USEPA on June 20, 1996, it was agreed that the 5% level would be acceptable.

Comment 2c: **Chromium Soil B--An incorrect interpretation is made for the Shapiro Wilk normality test. The calculated W exceeds the critical W, so the correct conclusion should be that the lognormally transformed data meet the assumption of normality (Parsons Engineering declares incorrectly that the lognormally transformed data do not meet the assumption of normality). The same incorrect conclusions were given for Lead horizon B.**

Response: Concur. Parsons ES incorrectly interpreted the Shapiro-Wilk test results for SWMU 17a and 17bcd for chromium and for lead in soil horizon B. These corrections have been made, but the corrections did not effect the results of the tolerance limit

comparisons.

Comment 2d: **The Normal Tolerance limits are incorrect. Parsons Engineering did not seem to multiply the tolerance factor (K) by the standard deviation. I observed this in the data set that I checked (Barium horizon b: which calculated the upper tolerance limit by adding to the mean the kappa factor without first multiplying the kappa factor by the standard deviation). It appears as though all other normal tolerance limits were calculated the same way. The poisson based tolerance limit calculations appear to be correct.**

Response: Concur. The normal tolerance limits were recalculated using the correct formula. The results remain the same for all analyses with the exception that there are no longer exceedances for barium or lead in SWMU 17a, soil horizon B.

Comment 3: **The tail area probability "tests" provided for the sediments data are not very revealing. What criteria are used to evaluate samples? Was the Shapiro-Wilk test used to determine whether the normal or lognormal tail area probabilities would be calculated?**

Response: Concur. Parsons ES chose the tail area probability comparison as a crude estimate of differences between sediment metals SWMU samples vs. background based on the limited number of background and SWMU sediment metals samples to be collected.

RESPONSE TO USEPA REGION III

Part II. Response to comments dated June 1996 from Mary Beck, U.S. EPA Region III on the *Draft RCRA Facility Investigation Report.*

Comment 1: **Table 6-14 is not completely legible. All tables, charts, maps, etc. must be legible and capable of being scanned.**

Response: Concur. This table will be reformatted.

Comment 2: **Appendix F - Geotechnical Data, the written description does not always match the Unified Soil Classification System, e.g., Sample BG5BWL3 description is brown clayey silt where the USCS symbol is SC (clayey sand).**

Response: The geotechnical data presented in Appendix F was prepared by a geotechnical laboratory subcontracted by Parsons ES. Discrepancies between the USCS classifications and soil descriptions are due to the fact that the soil descriptions are qualitative and done independently of the more quantitive USCS soil classification.

Comment 3: **Appendix F - Visual Manual Soil Classification Data Summary, the USCS symbols do not always match the previous table, e.g., here the symbol for sample BG5BWL3 is CL and on the previous table the symbol is SC.**

Response: The USCS symbols presented in the Visual Manual Soil Classification Data Summary were generated by a Parsons ES geologist using visual manual procedures. Because these procedures utilize different criteria to classify soil types (e.g., toughness and plasticity) than those employed by the geotechnical lab, some discrepancies have occurred.

Comment 4: **Appendix H, the pages must be numbered.**

Response: Concur.

Comment 5: **Appendix H, the Positive Results Table of Background Soil Samples needs to include the sample detection level (<DL) where the constituent was not detected.**

Two different samples have the same identification.

Include a version of Table 2, Revised Addendum to the Final RCRA Facility Work Plan as a key to the sample identification scheme.

Response: Concur. The detection levels will be added to the Positive Results Table for background samples in Appendix H.

Concur. The second sample should read BG2BUC5. This correction will be made.

Concur. A version of Table 2 will be added to Appendix H.

Comment 6: **Appendix H, each page where a data set was checked for normality needs to identify the soil series and horizon being tested.**

Response: Non-concur. The data is currently presented in sections by soil type. The soil horizons are listed at the top of each page.

Comment 7: **Appendix H, the 1% significance level is to be used to check data sets for normality.**

Response: Resolved in the June 20, 1996, meeting with USEPA. See response to comment 2b in Part I above.

Comment 8: **Appendix H, there is no indication that the non detects (NDs) were handled as identified in the Work Plan Addendum dated June 1995.**

Response: As indicated in paragraph 4.4.0.1. of the RFI Report, statistical analysis were done in accordance with the Revised Addendum to the Work Plan, Parsons ES, June 1995.

Comment 9: **Appendix H, all Tolerance Level calculations need to be reviewed to determine if the appropriate method was used and if the calculations are done accurately.**

The Poisson-based Tolerance Limit is used when there is a high percentage of Nos. In at least one calculation (other calculations were not reviewed), Poisson-based Tolerance Limit procedure was employed when there are only three NDs in a data set of eight. Please explain.

Response: See response to commend 2d in Part I above.

As described in paragraphs 6.2.2.1.4 and 6.2.2.1.5 in the RFI report, the Poisson-based Tolerance limit was used in two circumstances. (1) when the background distribution had >50% non-detect (ND) values; and (2) when the percentage of non-detects was 15% < ND <50% and the Shapiro-Wilk test determined that the distribution of detected values was non-normal.

Comment 10: **Appendix H, produce a table identifying the upper Tolerance Level for each soil series, horizon, and constituent analyzed.**

Response: Concur.

Hand Written Comment 1: **P 7-37 only active military explosives manufacturing facility.**

Response: Page 7-37 does not appear to be relevant to this comment. However, this comment does appear to be relevant to paragraph 6.5.1.1.1 and Parsons ES will make the appropriate change.

Hand Written Comment 2: **P 6-35 6.5.1.1.1 and p 6-78 6.5.3.3.9 references to industrial vs. residential risk assessment exposure scenarios. RCRA requires a residential evaluation.**

Response: The residential exposure scenario was not considered because it is unlikely that this facility will be used for residential purposes. However, Parsons ES will calculate exposure levels based on a residential scenario to provide data for comparison to the current risk assessment. The Army does not intend to incorporate these residential exposure scenarios into the current risk assessment.

Hand Written Comment 3: **Section 7.7.1 change chromium III to chromium on page 7-38.**

Response: Concur.

[redacted]

file

Alliant Techsystems Inc.
Radford Army Ammunition Plant
Route 114
P.O. Box 1
Radford, VA 24141-0100

January 16, 1995

96-815-018

U. S. Environmental Protection Agency
Region III
841 Chestnut Building
Philadelphia, PA 19107-4431

Attention: Mr. Robert Greeves, EPA Region III, Regional Administrator

Subject: Radford Army Ammunition Plant, VA1 21 002 0730,
RFI for SWMUs 17, 31, 48, & 54

Dear Sir:

In accordance with the RCRA Corrective Actions Permit for Radford Army Ammunition Plant VA1 21 002 0730, enclosed are three copies of the RCRA Facility Investigation for Solid Waste Management Units 17, 31, 48, & 54.

If you have any questions or comments please contact either myself or Jerry Redder of my staff at (540) 639-7536.

Sincerely,

C. A. Jake

C. A. Jake
Environmental Manager

Attachment

c: w/ enclosure under separated cover
Robert Thomson, P.E., EPA Region III
Hassan Vakili, Virginia Department of Environmental Quality
Erica Damron, Virginia Department of Environmental Quality
Harry Kleiser, Army Environmental Center
Robert Davie, Army Environmental Center
John Segna, Parsons Engineering Science, Inc.

Concerning the following document:

The RCRA Facility Investigation Report for Solid Waste Management Units 17, 31, 48, and 54 at Radford Army Ammunition Plant, Virginia.

I certify under penalty of law that this document and all attachments were prepared under my direction or supervision in accordance with a system designed to assure that qualified personnel properly gather and evaluate the information submitted. Based on my inquiry of the person or persons who manage the system, or those persons directly responsible for gathering the information, the information submitted is, to the best of my knowledge and belief, true, accurate, and complete. I am aware that there are significant penalties for submitting false information, including the possibility of fines and imprisonment for knowing violations.

SIGNATURE: John R. Loyd

PRINTED NAME: JOHN R. LOYD

TITLE: LTC, OD, Commanding
Radford Army Ammunition Plant

SIGNATURE: James E. Woolwine

PRINTED NAME: JAMES E. WOOLWINE

TITLE: Resident Manager
Alliant Techsystems Inc.

RCRA FACILITY INVESTIGATION FOR SOLID WASTE MANAGEMENT UNITS 17, 31, 48, AND 54 AT RADFORD ARMY AMMUNITION PLANT, VIRGINIA

PREPARED FOR:

U. S. ARMY ENVIRONMENTAL CENTER

Aberdeen Proving Ground, Maryland

PREPARED BY:

PARSONS ENGINEERING SCIENCE, INC.

10521 Rosehaven Street
Fairfax, Virginia 22030

JANUARY 1996

DISTRIBUTION LIST	COPIES
Mr. Robert Davie Project Manager U.S. Army Environmental Center Building E-4480 Aberdeen P.G., Maryland 21010-5041	(2)
Mr. Bob Richardson U.S. Army Radford Army Ammunition Plant Radford, Virginia 24141-0100	(1)
Mr. Jerry Redder Alliant Techsystems Radford Army Ammunition Plant Radford, Virginia 24141-0100	(1)
Ms. Mary Beck U.S. Environmental Protection Agency RCRA Programs Branch (3HW52) 841 Chestnut Building Philadelphia, PA 19107-4431	(3)
Mr. Robert Thompson U.S. EPA Office of Superfund (3HW71) 841 Chestnut Building Philadelphia, PA 19107-4431	(1)
Ms. Erica Dameron Virginia Department of Environmental Quality 629 East Main street Richmond, Virginia 23219	(2)
Mr. Hassan Vakili Virginia Department of Environmental Quality 4900 Cox Road Glenn Allen, Virginia 24060	(1)

RCRA FACILITY INVESTIGATION REPORT
RADFORD ARMY AMMUNITION PLANT
RADFORD, VIRGINIA

TABLE OF CONTENTS

PAGE

EXECUTIVE SUMMARY ES-1

SECTION 1 INTRODUCTION

1.1 Introduction 1-1
1.2 Project Objectives 1-2
1.3 Scope of Work 1-3
1.4 Report Organization 1-4

SECTION 2 FACILITY DESCRIPTION

2.1 Facility Location 2-1
2.2 Facility History 2-5
2.3 Facility Responsibility 2-6
2.4 Industrial Operations 2-8

2.4.1 Propellant Production 2-9
2.4.2 TNT Production 2-10
2.4.3 Secondary Manufacturing Operations 2-11

2.5 Summary of Previous Investigations 2-12

SECTION 3 ENVIRONMENTAL SETTING

3.1 Climate 3-1
3.2 Physiography 3-1
3.3 Land Use/Demographics 3-4
3.4 Regional Soils 3-5

3.4.1 Soil Type 1: Fluvaquents 3-5
3.4.2 Soil Type 2: Wheeling Sandy Loam 3-8
3.4.3 Soil Type 3: Cotaco Loam 3-9
3.4.4 Soil Type 4: Braddock Loam 3-9
3.4.5 Soil Type 5: Carbonate Rock Outcrop 3-10
3.4.6 Soil Type 6: Unison-Urban Land Complex 3-10
3.4.7 Soil Type 7: Udorthents and Urban Land 3-11
3.4.8 Soil Type 8: Ross Soils 3-11
3.4.9 Soil Type 9: Caneyville-Opequon-Rock Outcrop Complex 3-11
3.4.10 Soil Type 10: Mixed Soil Types 3-12

3.5 Regional Geology 3-12

3.5.1 Regional Geology of the Southern Appalachian Valley and Ridge Province 3-12
3.5.2 Structural History of the Southern Appalachian Valley and Ridge Province 3-14
3.5.3 Geology of RAAP 3-15

3.6 Regional Hydrogeology 3-32
3.7 Surface Water Hydrology 3-38
3.8 Groundwater Usage 3-43
3.9 Ecology 3-44

SECTION 4 FIELD INVESTIGATION PROGRAM

4.1 Overview 4-1
4.2 Drilling Procedures 4-2

4.2.1 Soil Borings 4-2
4.2.2 Monitoring Wells 4-3

4.3 Monitoring Well Completion Procedures 4-4

4.3.1 Monitoring Well Construction 4-4
4.3.2 Monitoring Well Development 4-7

4.4 Soil Background Metals Study 4-7
4.5 Dye Tracing Study 4-8

4.5.1 Well Installation 4-8
4.5.2 Dye Selection 4-9
4.5.3 Dye Injection 4-9
4.5.4 Dye Monitoring 4-10

4.6 Surface Water Elevation Gauge Installation 4-11
4.7 Aquifer Testing 4-12
4.8 Surveying 4-13
4.9 Sampling and Analysis Program 4-14

4.9.1 Surface Water 4-14
4.9.2 Groundwater 4-25
4.9.3 Soil 4-27

4.9.3.1 Surface Soils 4-27
4.9.3.2 Subsurface Soils 4-28
4.9.3.3 Geotechnical Samples 4-30

4.9.4 Sediment 4-30

4.9.4.1 Surface Water Bodies 4-32
4.9.4.2 Lagoons 4-32

4.9.5 Waste 4-33

4.10 Investigation Derived Waste 4-33

SECTION 5 DATA MANAGEMENT/DATA QUALITY

5.1 Data Management 5-1

5.1.1 Site Identification 5-1
5.1.2 Data and Data File Types 5-2
5.1.3 Data Development and Tracking 5-2
5.1.4 Problem Resolution 5-4

5.2 Data Quality 5-5

5.2.1 January 1995 Sampling Event 5-6

5.2.1.1 Summary 5-6
5.2.1.2 Minor Problems 5-7

5.2.2 July 1995 Sampling Event 5-9

5.2.2.1 Summary 5-9
5.2.2.2 Minor Problems 5-10
5.2.2.3 Glossary of Data Validation Qualifiers 5-11

SECTION 6 BASELINE RISK ASSESSMENT

6.1 Introduction 6-1

6.1.1 Objectives 6-1
6.1.2 Overview and General Approach 6-2

6.2 Selection of Chemicals of Concern 6-3

6.2.1. Evaluation of Analytical Data 6-8
6.2.2 Comparison to Background 6-9

6.2.2.1 Methodology 6-10
6.2.2.2 Results 6-12

6.2.3 Summary of Chemicals of Potential Concern 6-24

6.3 Compliance with Environmental Standards 6-24

6.3.1. Chemical-Specific ARARs and TBC Criteria 6-24

6.3.1.1. Groundwater 6-26
6.3.1.2 Surface Water and Sediments 6-26
6.3.1.3 Soils 6-27

6.3.2 Location and Action-Specific ARARs 6-27

6.3.2.1 Wetlands 6-28
6.3.2.2 Wildlife 6-28

6.4 Fate and Transport of the Chemicals of Potential Concern 6-29

6.4.1 Potential Routes of Migration 6-29
6.4.2 Contaminant Characteristics 6-30
6.4.3 Contaminant Migration and Persistence 6-32

6.5 Risk Assessment Methodology 6-34

6.5.1 Exposure Assessment 6-34

6.5.1.1 Identification of Potential Receptors 6-35
6.5.1.2 Identification of Exposure Pathways 6-37
6.5.1.3 Quantification of Exposure Pathways 6-37
6.5.1.4 Determination of Exposure Point Concentration 6-61

6.5.2 Toxicity Assessment 6-61

6.5.2.1 Health Criteria for Non-Carcinogenic Effect 6-63
6.5.2.2 Health Criteria for Carcinogenic Effects 6-63
6.5.2.3 Identified Carcinogens in Chemical of Concern List 6-67
6.5.2.4 Inhalation Exposure 6-68
6.5.2.5 Dermal Exposure 6-72

6.5.3 Risk Characterization 6-72

6.5.3.1 Non-Carcinogenic Effects 6-73
6.5.3.2 Carcinogenic Effects 6-74
6.5.3.3 Uncertainty Analysis 6-75

SECTION 7 SITE CHARACTERIZATION OF SWMU 17 AND SWMU 40 (CONTAMINATED WASTE BURNING AREAS AND SANITARY LANDFILL)

7.1 History and Operations 7-1

7.1.1 SWMU 17A: Stage and Burn Area 7-1
7.1.2 SWMU 17B: Air Curtain Destructor (ACD) Staging Area 7-3
7.1.3 SWMU 17C: Air Curtain Destructor (ACD) 7-3
7.1.4 SWMU 17D: Ash Staging Area 7-3
7.1.5 SWMU 17E: Runoff Drainage Basin 7-4
7.1.6 SWMU 40: Sanitary Landfill 7-4

7.2 Previous Investigations 7-4

7.2.1 SWMU 17A 7-8
7.2.2 SWMU 17B 7-9
7.2.3 SWMU 17C 7-9
7.2.4 SWMU 17D 7-10
7.2.5 SWMU 17E 7-10

7.2.6 SWMU 40 7-11

7.3 Summary of RFI Field Activities 7-11

7.3.1 SWMU 17A 7-11
7.3.2 SWMU 17B 7-13
7.3.3 SWMU 17C 7-13
7.3.4 SWMU 17D 7-13
7.3.5 SWMU 17 (Vicinity) 7-13

7.4 Environmental Setting 7-14

7.4.1 Topography and Site Layout 7-14
7.4.2 Geology 7-16
7.4.3 Hydrogeology 7-18
7.4.4 Surface Water 7-22

7.5 Nature and Extent of Contamination 7-23

7.5.1 Nature of Contamination (SWMU 17A) 7-23

7.5.1.1 Surface Soils 7-23
7.5.1.2 Subsurface Soils 7-31

7.5.2 Nature of Contamination (SWMU 17B,C,D) 7-31

7.5.2.1 Surface Soils 7-31
7.5.2.2 Subsurface Soils 7-32

7.5.3 Nature of Contamination (Vicinity) 7-33

7.5.3.1 Groundwater 7-33

7.5.4 Extent of Contamination (17A) 7-33

7.5.4.1 Surface Soils 7-33
7.5.4.2 Subsurface Soils 7-33

7.5.5 Extent of Contamination (17B,C,D) 7-34

7.5.5.1 Surface Soils 7-34
7.5.5.2 Subsurface Soils 7-34

7.5.6 Extent of Contamination (Vicinity) 7-35

7.5.6.1 Groundwater 7-35

7.6 Contaminant Fate and Transport 7-36
7.7 Risk Assessment 7-37

7.7.1 Summary of Chemicals of Potential Concern (COCs) 7-38

7.7.1.1 Comparison to ARARs and TBCs for Groundwater and Soils 7-38

7.7.2 Exposure Assessment 7-39

7.7.2.1 Potential Pathways and Receptors 7-39
7.7.2.2 Estimation of Exposure Point Concentrations and Chronic Daily Intakes 7-39

7.7.3 Risk Characterization 7-41

7.7.3.1 Noncarcinogenic Effects 7-41
7.7.3.2 Carcinogenic Effects 7-42

7.7.4 Uncertainty Analysis 7-43

7.8 Risk Summary 7-44
7.9 SWMU 17/40 Summary 7-47

SECTION 8 SITE CHARACTERIZATION OF SWMU 31 (COAL ASH SETTLING LAGOONS)

8.1 History and Operations 8-1
8.2 Previous Investigations 8-3
8.3 Summary of RFI Field Activities 8-7
8.4. Environmental Setting 8-9

8.4.1 Topography and Site Layout 8-9
8.4.2 Geology 8-9
8.4.3 Hydrogeology 8-12

8.4.3.1. Aquifer Testing Results 8-16

8.4.4 Surface Water 8-18

8.5 Nature and Extent of Contamination 8-19

8.5.1 Nature of Contamination 8-19

8.5.1.1 Subsurface Soils 8-19
8.5.1.2. Groundwater 8-19

8.5.2 Extent of Contamination 8-23

8.5.2.1 Subsurface Soils 8-23
8.5.2.2 Groundwater 8-24

8.6 Contaminant Fate and Transport 8-24
8.7 Risk Assessment 8-25

8.7.1 Summary of Chemicals of Potential Concern 8-25

8.7.1.1 Comparison to ARARs and TBCs for Groundwater 8-26

8.7.2 Exposure Assessment 8-26

8.7.2.1 Potential Pathways and Receptors 8-26
8.7.2.2 Exposure Point Concentrations and Chronic Daily Intakes 8-27

8.7.3 Risk Characterization 8-27

8.7.3.1 Noncarcinogenic Effects 8-27
8.7.3.2 Carcinogenic Effects 8-27

8.7.4 Uncertainty Analysis 8-29

8.8 Risk Summary 8-29
8.9 SWMU 31 Summary 8-30

SECTION 9 SITE CHARACTERIZATION OF SWMU 48 (OILY WASTEWATER DISPOSAL AREA)

9.1 History and Operations 9-1
9.2 Previous Investigations 9-1
9.3 Summary of RFI Field Activities 9-7
9.4. Environmental Setting 9-8

9.4.1 Topography and Site Layout 9-8
9.4.2 Geology 9-10
9.4.3 Hydrogeology 9-14

9.4.3.1 Aquifer Testing Results 9-16

9.4.4 Surface Water 9-19

9.5 Nature and Extent of Contamination 9-19

9.5.1 Nature of Contamination 9-24

9.5.1.1 Surface Soils 9-24
9.5.1.2 Subsurface Soil 9-25
9.5.1.3 Groundwater 9-25

9.5.2. Extent of Contamination 9-26

9.5.2.1 Surface Soils 9-26
9.5.2.2 Sursurface Soils 9-27
9.5.2.3 Groundwater 9-28

9.6 Contaminant Fate and Transport 9-29
9.7 Risk Assessment 9-30

9.7.1 Summary of Chemicals of Potential Concern 9-30

9.7.1.1 Comparison to ARARs and TBCs for Groundwater and Soils 9-30

9.7.2 Exposure Assessment 9-31

9.7.2.1 Potential Pathways and Receptors 9-31
9.7.2.2 Exposure Point Concentrations and Chronic Daily Intakes 9-31

9.7.3 Risk Characterization 9-33

9.7.3.1 Noncarcinogenic Effects 9-33
9.7.3.2 Carcinogenic Effects 9-33

9.7.4 Uncertainty Analysis 9-35

9.8 Risk Summary 9-36
9.9 SWMU 48 Summary 9-36

SECTION 10 SITE CHARACTERIZATION OF SWMU 54 (PROPELLANT ASH DISPOSAL AREA)

10.1 History and Operations 10-1
10.2 Previous Investigations 10-1
10.3 Summary of RFI Field Activities 10-5
10.4. Environmental Setting 10-5

10.4.1 Topography and Site Layout 10-5
10.4.2 Geology 10-8
10.4.3 Hydrogeology 10-8
10.4.4 Surface Water 10-10

10.5 Nature and Extent of Contamination 10-13

10.5.1 Nature of Contamination 10-13

10.5.1.1. Subsurface Soils 10-13
10.5.1.2. Groundwater 10-20

10.5.2 Extent of Contamination 10-20

10.5.2.1. Subsurface Soils 10-20
10.5.2.2. Groundwater 10-21

10.6 Contaminant Fate and Transport 10-21
10.7 Risk Assessment 10-22

10.7.1 Summary of Chemicals of Potential Concern 10-23

10.7.1.1 Comparison to ARARs and TBCs for Groundwater and Soils 10-23

10.7.2 Exposure Assessment 10-23

10.7.2.1 Potential Pathways and Receptors 10-23
10.7.2.2 Exposure Point Concentrations and Chronic Daily Intakes 10-24

10.7.3 Risk Characterization 10-24

10.7.3.1 Noncarcinogenic Effects 10-24
10.7.3.2 Carcinogenic Effects 10-26

10.7.4 Uncertainty Analysis 10-26

10.8 Risk Summary 10-28
10.9 SWMU 54 Summary 10-28

SECTION 11 SITE CHARACTERIZATION OF STROUBLES CREEK

11.1 Environmental Setting 11-1
11.2 Previous Investigations 11-1
11.3 Summary of RFI Field Activities 11-3
11.4 Nature and Extent of Contamination 11-3

11.4.1 Nature of Contamination 11-7

11.4.1.1 Sediment 11-7
11.4.1.2 Surface Water 11-7

11.4.2 Extent of Contamination 11-8

11.4.2.1 Sediment 11-8
11.4.2.2 Surface Water 11-8

11.5 Contaminant Fate and Transport 11-8
11.6 Risk Assessment 11-9

11.6.1 Summary of Chemicals of Potential Concern 11-10

11.6.1.1 Comparison to ARARs and TBCs for Groundwater and Soils 11-10

11.6.2 Exposure Assessment 11-10

11.6.2.1 Potential Pathways and Receptors 11-10
11.6.2.2 Exposure Point Concentrations and Chronic Daily Intakes 11-11

11.6.3 Risk Characterization 11-11

11.6.3.1 Noncarcinogenic Effects 11-11
11.6.3.2 Carcinogenic Effects 11-11

11.6.4 Uncertainty Analysis 11-14

11.7 Risk Summary 11-15
11.8 Stroubles Creek Summary 11-17

SECTION 12 SITE CHARACTERIZATION OF THE NEW RIVER

12.1 Environmental Setting 12-1
12.2 Previous Investigations 12-2
12.3 Summary of RFI Field Activities 12-7
12.4 Nature and Extent of Contamination 12-12

12.4.1 Nature of Contamination 12-19

12.4.1.1 Sediment 12-19
12.4.1.2 Surface Water 12-20

12.4.2 Extent of Contamination 12-20

12.4.2.1 Sediment 12-20
12.4.2.2 Surface Water 12-20

12.5 Contaminant Fate and Transport 12-21
12.6 Risk Assessment 12-21

12.6.1 Summary of Chemicals of Potential Concern 12-22

12.6.1.1 Comparison to ARARs and TBCs for Groundwater and Soils 12-22

12.6.2 Exposure Assessment 12-22

12.6.2.1 Potential Pathways and Receptors 12-22
12.6.2.2 Exposure Point Concentrations and Chronic Daily Intakes 12-23

12.6.3 Risk Characterization 12-23

12.6.3.1 Noncarcinogenic Effects 12-25
12.6.3.2 Carcinogenic Effects 12-25

12.6.4 Uncertainty Analysis 12-26

12.7 Risk Summary 12-27
12.8 New River Summary 12-27

SECTION 13 RECOMMENDATIONS

13.1 SWMU 17 (Contaminated Waste Burning Areas) SWMU 40 (Sanitary Landfill) 13-1

13.1.1 Recommendations 13-1

13.2 SWMU 31 (Coal Ash Settling Lagoons) 13-3

13.2.1 Recommendations 13-3

13.3 SWMU 48 (Oily Wastewater Disposal Area) 13-4
13.3.1 Recommendations 13-4
13.4 SWMU 54 (Propellant Ash Disposal Area) 13-4
13.4.1 Recommendations 13-4
13.5 Stroubles Creek 13-5
13.6 New River 13-5
13.6.1 Recommendations 13-5
SECTION 14 REFERENCES

LIST OF APPENDICES

APPENDIX	A	Acronyms and Abbreviations
	B	Groundwater Usage - Well Inventory
	C	Lithologic Logs/Well Construction Records
	D	Monitoring Well Development - Field Data Sheets
	E	Aquifer Testing Data
	F	Geotechnical Data
	G	Data Validation Report/Data Summary Tables
	H	Summary Statistics for Background Distributions
	I	Risk Assessment

PLATES

PLATE 1	Topographic Map and SWMU Locations
PLATE 2	Facility-Wide Groundwater Gradient Map
PLATE 3A	Location of Water Supply Wells in the Vicinity of RAAP, Pulaski County
PLATE 3B	Location of Water Supply Wells in the Vicinity of RAAP, Montgomery County

LIST OF FIGURES

2.1	Location Map	2-2
2.2	RAAP and Vicinity Map	2-3
2.3	Main Section of RAAP	2-4
3.1	Soil Types and SWMU Location Map	3-7
3.2	Geologic Map of the Pulaski Thrust Sheet in the Vicinity of RAAP	3-17
3.3	Bedrock Geologic Map of RAAP	3-19
3.4	Geologic Cross Section A-A' of RAAP and Adjacent Areas	3-25
3.5	Geologic Cross Section B-B' of RAAP and Adjacent Areas	3-26
3.6	Photograph of an Outcrop of the Max Meadows Breccia	3-27
3.7	Photograph of an Outcrop of the Elbrook Formation	3-28
3.8	Outcrop Sections in the Vicinity of RAAP	3-29
3.9	Geologic Map of RAAP Showing River Terrace Deposits	3-31
3.10	Fracture Trace/Sinkhole Location Map of RAAP	3-33
3.11	Surface Water Drainage/Outfall Locations	3-42
4.1	Typical Monitoring Well Construction	4-5
5.1	IRDMIS Data Management Phases	5-3
7.1	Location Map - SWMU 17/SWMU 40	7-2
7.2	Sample Location Map - SWMU 17/SWMU 40	7-12
7.3	SWMU 17/SWMU 40 Geologic Cross Section (A-A')	7-17
7.4	SWMU 17/SWMU 40 Groundwater Potentiometric Surface Map	7-20
7.5	SWMU 17 ABCD Conceptual Site Model for Current and Future Exposure Pathways	7-40
8.1	Location Map - SWMU 31	8-2
8.2	Sample Location Map - SWMU 31	8-4
8.3	SWMU 31 Geologic Cross Section (A-A')	8-10
8.4	SWMU 31 Geologic Cross Section (B-B')	8-11
8.5	SWMU 31 Groundwater Potentiometric Surface Map	8-13
8.6	Conceptual Site Model for Current and Future Exposure Pathways (SWMU 48)	8-28
9.1	Location Map - SWMU 48	9-2
9.2	Sample Location Map - SWMU 48	9-4
9.3	SWMU 48 Cross Section (A-A')	9-11
9.4	SWMU 48 Cross Section (B-B')	9-12
9.5	SWMU 48 Groundwater Potentiometric Surface Map	9-15
9.6	SWMU 48 Conceptual Site Model for Current and Future Exposure Pathways	9-32
10.1	Location Map - SWMU 54	10-2
10.2	Sample Location Map - SWMU 54	10-6
10.3	SWMU 54 Geologic Cross Section (A-A')	10-9
10.4	SWMU 54 Groundwater Potentiometric Surface Map	10-11

10.5 Conceptual Site Model for Current and Future Exposure Pathways - SWMU 54 10-25
11.1 Stroubles Creek Location Map 11-2
11.2 Conceptual Site Model for Current and Future Exposure Pathways - Stroubles Creek 11-12
12.1 New River Location Map 12-4
12.2 Conceptual Site Model for Current and Future Exposure Pathways - New River 12-24

LIST OF TABLES

ES-1 Summary of RFI Recommendations ES-8
2.1 Chronological List of Major Activities at RAAP 2-7
3.1 Average Monthly Precipitation for Locations Near RAPP 3-2
3.2 Average Monthly Temperatures for Locations Near RAAP 3-3
3.3 Population in the Vicinity of RAAP 3-6
3.4 Legend to the Bedrock Geologic Map of RAAP 3-18
3.5 Reference Locality Description 3-22
3.6 Legend to the Geologic Map of RAAP Showing River Terrace Deposits 3-30
3.7 Groundwater Elevation Summary 3-39
4.1 Monitoring Well Construction Details 4-6
4.2 Survey Data 4-15
4.3 RFI Analytical Program: Aqueous Samples 4-16
4.4 RFI Analytical Program: Solid Samples 4-18
4.5 Geotechnical Samplling RAAP 4-31
6.1 Maximum Soil Concentrations 6-4
6.2 Maximum Groundwater Concentrations 6-5
6.3 Maximum Sediment Concentrations 6-6
6.4 Maximum Surface Water Concentrations 6-7
6.5 Background Soil Types Associated SWMUs and Sample Numbers 6-11
6.6 SWMU17A, Soil Horizon B 6-14
6.7 SWMU17A, Soil Horizon C 6-15
6.8 SWMU17B,C,D Soil Horizon B 6-17
6.9 SWMU 17B,C,D Soil Horizon C 6-18
6.10 SWMU 31,Soil Horizon C 6-20
6.11 SWMU 54, Soil Horizon B 6-21
6.12 SWMU 54, Soil Horizon C 6-22
6.13 Water Quality Criteria 6-26
6.14 Environmental Properties, Fate and Transport Data [(a)] 6-31
6.15 Exposure Parameters and Intake Algorithm for Current Site Worker Exposure: Surface Soil Ingestion 6-40
6.16 Exposure Paramaters and Intake Algorithm for Current Site Worker Exposure: Surface Soil Dermal Contact 6-41
6.17 Exposure Parameters and Intake Algorithm for Current Site Worker Exposure: Inhalation of Surface Soil Volatiles and Particulates 6-42
6.18 Exposure Parameters and Intake Algorithm for Current Site Worker Exposure: Ingestion of Surface Water 6-43
6.19 Exposure Parameters and Intake Algorithm for Current Site Worker Exposure: Dermal Contact with Surface Water 6-44
6.20 Exposure Parameters and Intake Algorithm for Current Site Worker Exposure: Sediment Ingestion 6-45

6.21 Exposure Parameters and Intake Algorithm for Current Site Worker Exposure: Sediment Dermal Contact 6-46
6.22 Exposure Parameters and Intake Algorithm for Current Recreational Surface Water Users: Ingestion of Chemicals in Surface Water 6-47
6.23 Exposure Parameters and Intake Algorithm for Current Recreational Surface Water Users: Dermal Contact with Chemicals in Surface Water 6-48
6.24 Exposure Parameters and Intake Algorithm for Incidental Ingestion of Surface Water by Fisherman 6-49
6.25 Exposure Parameters and Intake Algorithm for Dermal Contact with Surface Water by Fisherman 6-50
6.26 Exposure Parameters and Intake Algorithm for Ingestion of Contaminated Fish by Fisherman 6-51
6.27 Exposure Parameters and Intake Algorithm for Recreational Hunter Exposure: Surface Soil Ingestion 6-52
6.28 Exposure Parameters and Intake Algorithm for Recreational Hunter Exposure: Surface Dermal Contact 6-53
6.29 Exposure Parameters and Intake Algorithm for Future Recreational Hunter Exposure: Ingestion of Contaminated Meat 6-54
6.30 Exposure Parameters and Intake Algorithm for Future Residential Adult Exposure: Surface Soil Ingestion 6-55
6.31 Exposure Parameters and Intake Algorithm for Future Residential Child Exposure: Surface Soil Ingestion 6-56
6.32 Exposure Parameters and Intake Algorithm for Future Residential Adult Exposure: Surface Soil Dermal Contact 6-57
6.33 Exposure Parameters and Intake Algorithm for Future Residential Child Exposure: Surface Soil Dermal Contact 6-58
6.34 Exposure Parameters and Intake Algorithm for Future Residential Exposure: Inhalation of Soil Volatiles and Particulates 6-59
6.35 Exposure Parameters and Intake Algorithm for Future Residential Adult Exposure: Ingestion of Groundwater 6-60
6.36 Exposure Parameters and Intake Algorithm for Future Residential Adult Exposure: Dermal Contact with Groundwater 6-64
6.37 Exposure Parameters and Intake Algorithm for Future Residential Adult Exposure: Inhalation of Groundwater While Showering 6-66
7.1 RFI Data 1992 - SWMU 17 Soil 7-5
7.2 RFI Data 1992 - SWMU 17 Surface Water 7-6
7.3 RFI Data 1992 - SWMU 17 Sediment 7-7
7.4 Summary of SWMU 17/40 RFI Field Activities 7-15
7.5 SWMU 17: Groundwater Field Data 7-21
7.6 SWMU 17a: Solid Samples 7-24
7.7 SWMU 17b, 17c, 17d: Solid Samples 7-27
7.8 SWMU 17 Vicinity: Aqueous Samples 7-30

7.9 SWMU 17a: Summary of Human Health Risk 7-45
7.10 SWMU 17bcd: Summary of Human Health Risk 7-46
8.1 VI Data 1992 - SWMU 31 Sediment 8-5
8.2 Summary of SWMU 31 RFI Field Activities 8-8
8.3 SWMU 31: Groundwater Field Data 8-15
8.4 Summary of Slug Testing Data 8-17
8.5 Positive Results SWMU 31 - Solid Samples 8-20
8.6 Positive Results SWMU 31 - Aqueous Samples 8-22
8.7 Summary of Human Health Risks 8-31
9.1 VI Data 1991 - SWMU 48 Soil 9-5
9.2 Summary of SWMU 48 RFI Field Activities 9-9
9.3 SWMU 48 Groundwater Field Data 9-17
9.4 Summary of Slug Testing Data SWMU 48 9-18
9.5 SWMU 48 Solid Samples 9-20
9.6 SWMU 48 Aqueous Samples 9-23
9.7 SWMU 48 Summary of Human Health Risk 9-37
10.1 VI Data 1992 - SWMU 54 Groundwater 10-4
10.2 Summary of SWMU 54 RFI Field Activities 10-7
10.3 SWMU 54 Groundwater Field Data 10-12
10.4 Positive Results of SWMU 54 - Solid Samples 10-14
10.5 Positive Results of SWMU 54 - Aqueous Samples 10-19
10.6 Summary of Human Health Risk - SWMU 54 10-29
11.1 Summary of Analytical Data for Surface Water Samples SWMU 41 ... 11-4
11.2 Positive Results of Stroubles Creek - Sediment Samples 11-5
11.3 Positive Results of Stroubles Creek - Aqueous Samples 11-6
11.4 Summary of Human Health Risk Stroubles Creek 11-16
12.1 Summary of Analytical Data for Sediment Samples SWMU 13 12-5
12.2 Summary of Analytical Data for Surface Water Samples SWMU 13 ... 12-8
12.3 Summary of New River RFI Field Activities 12-11
12.4 Positive Results Table of New River Sediment Samples 12-13
12.5 Positive Results Table of New River Aqueous Samples 12-14
12.6 New River Surface Water 12-17
12.7 New River Sediments 12-18
12.8 Summary of Human Health Risk - New River 12-28
13.1 Summary of RFI Recommendations 13-7

LIST OF ACRONYMS AND ABBREVIATIONS

ACD	Air Curtain Destructor
ACL	Alternate Concentration Limit
ACO	Administrative Contracting Officer
ARARs	Applicable or Relevant and Appropriate Requirements
ASTM	American Society for Testing and Materials
atm-m^3/mole	Atmosphere - cubic meter per mole
BCF	Bioconcentration Factor
BCM	Betz-Converse-Murdock, Inc.
bgs	Below Ground Surface
BTU	British Thermal Unit
CAA	Clean Air Act
CBC	Complete Blood Count
CL	Silty Clay
CIH	Certified Industrial Hygienist
CMS	Corrective Measures Study
COC	Chain of Custody
COD	Chemical Oxygen Demand
CRAVE	Carcinogenic Risk Assessment Verification Endeavor
CTM	Charles T. Main of Virginia, Inc.
CWA	Clean Water Act
dBA	Decibel
DCL	Data Chem Laboratories
DNT	Dinitrotoluene
E	Exposure Level
EM	Electromagnetic
EP	Extract Procedure
FAL	Fly Ash Landfill
FLFA	Former Lead Furnace Area
Fm.	Formation
FVC	Forced Vial Capacity
FWQC	Federal Water Quality Criteria
GCMS	Gas Chromatograph Mass Spectrometer
GM	Silty Gravel
GOCO	Government-owned, Contractor-operated
GW	Groundwater
HBN	Health-based Number
HEAST	Health Effects Assessment Summary Tables
HI	Hazard Index
HMX	High melting point explosive
HSP	Health and Safety Plan
HSWA	Hazardous and Solid Waste Amendments
ID	Identification Number
IR	Installation Restoration
IRDMIS	Installation Restoration Data Management Information System
IRFDS	Inhalation Reference Doses
ISF	Inhalation Slope Factor
IVR	Inhalation Unit Risks
KCl	Potassium Chloride
KoC	Organic Carbon (soils) Partition Coefficient
KoW	Octanol/water Partition Coefficient
LQAC	Laboratory QA Coordinator
MCL	Maximum Contaminant Level
MCLG	Maximum Contaminant Level Goals
MDL	Method Detection Limits
mg/kg	Milligrams Per Kilogram
mg/L	Milligrams Per Liter

LIST OF ACRONYMS AND ABBREVIATIONS

mgd	Million Gallons Per Day
ML	Sandy Silt
mm-Hg	Millimeters of Mercury
mph	Miles Per Hour
MSDS	Material Safety Data Sheet
msl	Mean Sea Level
MTBE	Methyl Tertiary Butyl Ether
MW	Monitoring Well
NBS	National Bureau of Standards
NC	Nitrocellulose
ND	Nondetect
NEIC	National Enforcement Investigation Center
NG	Nitroglycerin
NIST	National Institute of Standards and Technology
NROW	New River Ordnance Works
NRVPDC	New River Valley Planning District Commission
Parsons ES	Parsons Engineering Science, Inc.
PAHs	Polynuclear Aromatic Hydrocarbons
PC	Personal Computer
PEF	Particulate Emission Factor
PID	Photoionization Detector
PNA	Polynuclear Aromatic Hydrocarbons
PPE	Personal Protective Equipment
PQL	Practical Quantification Limit
psi	Pounds per Square Inch
PVC	Polyvinyl Chloride
QA	Quality Assurance
QAP	Quality Assurance Plan
QAPP	Quality Assurance Project Plan
QC	Quality Control
RAAP	Radford Army Ammunition Plant
RAGS	Risk Assessment Guidance for Superfund
RBC	Risk Based Concentration
RCRA	Resource Conservation and Recovery Act
RfC	Reference Concentration
RfD	Reference Dose
RFI	RCRA Facility Investigation
RL	Reporting Limit
RME	Reasonable Maximum Exposure
ROW	Radford Ordnance Works
RPD	Relative Percent Difference
RW	Drilling/Rinse Water
SB	Soil Boring
SCS	Soil Conservation Service
SE	Sediment
SES	Safety and Environmental Service
SF	Slope Factor
SM	Silty Sand
SO	Soil
SOP	Standard Operating Procedure
SS	Surface Soil
SVOC	Semivolatile Organic Compound
SW	Surface Water
SWMU	Solid Waste Management Unit
TAL	Target Analyte List

TBC	To Be Considered
TBD	To Be Determined
TCE	Trichloroethene
TCLP	Toxic Characteristic Leaching Procedure
TEFs	Toxicity Equivalency Factors
TIC	Tentatively Identified Compound
TNT	Trinitrotoluene
TOC	Top of Well Casing or Total Organic Carbon
TOX	Total Organic Halogens
TPH	Total Petroleum Hydrocarbon
µgg	Micrograms Per Gram
µg/L	Micrograms Per Liter
USAEC	U.S. Army Environmental Center
USAEHA	U.S. Army Environmental Hygiene Agency
USATHAMA	U.S. Army Toxic and Hazardous Materials Agency
USCS	Unified Soil Classification System
USDOT	U.S. Department of Transportation
USEPA	U.S. Environmental Protection Agency
UST	Underground Storage Tank
VDMR	Virginia Division of Mineral Resources
VI	Verification Investigation
VOC	Volatile Organic Compound
VPI&SU	Virginia Polytechnic Institute and State University
WQC	Walter Quality Criteria

EXECUTIVE SUMMARY

This document is the draft report for the Resource Conservation and Recovery Act (RCRA) Facility Investigation (RFI) for the Radford Army Ammunition Plant (RAAP), Radford, Virginia. It has been prepared for the U.S. Army Environmental Center (USAEC) by Parsons Engineering Science, Inc. (Parsons ES) and is being submitted under the requirements of Contract No. DAAA15-90-D-0008, Task DA04. RAAP is a government-owned contractor-operated (GOCO) military installation supplying solvent and solventless propellant grains and TNT explosives. The present contractor-operator is Alliant Techsystems, Inc.

RAAP was issued a Permit for Corrective Action and Incinerator Operation (Permit) by the U.S. Environmental Protection Agency (USEPA), effective December 13, 1989. The Permit requires RAAP to conduct RFIs for suspected releases of contamination from Solid Waste Management Units (SWMUs). The objective of the RFI is to characterize the nature, extent, concentration, and rate of migration of releases of hazardous wastes or hazardous constituents; identify potential receptors; provide detailed geologic and hydrogeologic characterizations; determine the need for corrective measures, or provide recommendations for other appropriate actions, for each SWMU.

Dames & Moore completed RFIs or Verification Investigations (VI) for all of the identified SWMUs in 1991-1992. Further characterization of certain SWMUs was recommended. This report contains the results of RFI activities at four SWMUs; SWMU 17, SWMU 31, SWMU 48, and SWMU 54. SWMU 40 was grouped with SWMU 17 because of geographical proximity and similar subsurface features. Additionally, characterization of the New River and Stroubles Creek, two significant surface water bodies at RAAP, was included in the RFI. The work was completed in general accordance with USEPA review comments on the previous Dames & Moore investigations, and the applicable guidance documents, including the RCRA Corrective Action Program Guide and the RCRA Corrective Action Manual.

RAAP is located in the mountains of southwestern Virginia, in Pulaski and Montgomery Counties. The facility consists of two noncontiguous areas; The Radford Unit (or Main Section) and the New River Storage Area Unit located about 6 miles west of the Main Section. The Main Section is the focus of this report. The New River divides the Main Section

into two areas. Within the meander loop of the New River is the "Horseshoe Area" and south of the New River is the "Main Manufacturing Area."

The SWMUs discussed in this report were characterized by drilling exploratory soil borings, installing groundwater monitoring wells, performing a structural geology study, a dye tracing study, and aquifer testing to investigate facility-wide and site-specific geology and hydrogeology, collecting groundwater, surface water, sediment, soil, waste ash, and associated QA/QC samples for chemical analysis, collecting soil samples for geotechnical testing, collecting composite soil or waste samples for disposal characterization, completing a study to establish background concentrations of metals occurring in the soils as the basis of statistical comparisons to metals levels found in the SWMU samples, and using the data to complete a quantitative human health risk assessment.

A summary of the RFI field activities implemented at each SWMU is presented below.

SWMU 17/SWMU 40 (CONTAMINATED WASTE BURNING AREAS AND SANITARY LANDFILL) The RFI investigation at SWMU 17/SWMU 40 consisted of performing a dye tracing study, drilling seven soil borings, collecting 42 soil samples, collecting one sediment sample, collecting one surface water sample, collecting four groundwater samples, and collecting appropriate QA/QC samples to ensure data usability.

SWMU 31 (COAL ASH SETTLING LAGOONS) The RFI investigation at SWMU 31 consisted of installing four wells, performing aquifer testing of the wells, placing staff gauges in the lagoons, collecting eight soil samples and six lagoon sediment samples, collecting four groundwater samples, and collecting appropriate QA/QC samples.

SWMU 48 (OILY WASTEWATER DISPOSAL AREA) The RFI investigation at SWMU 48 consisted of drilling two soil borings, installing four wells, performing aquifer testing of the wells, collecting 18 soil samples, collecting four groundwater samples, and collecting appropriate QA/QC samples.

SWMU 54 (PROPELLANT ASH DISPOSAL AREA) The RFI investigation at SWMU 54 consisted of drilling 16 soil borings, collecting 33 soil samples, collecting three groundwater samples, collecting two waste ash samples, and collecting appropriate QA/QC samples.

Additional field sampling activities were conducted in support of the RFI activities.

STROUBLES CREEK Two surface water samples and two sediment samples were collected from Stroubles Creek. Appropriate QA/QC samples were collected.

NEW RIVER Six surface water samples and six sediment samples were collected from the New River. Appropriate QA/QC samples were collected.

Finally, a study to determine background concentrations of metals in the soil was completed by drilling 16 soil borings and collecting 36 soil samples. QA/QC sampling was also performed for these investigations. Data from these areas were used to support the characterizations of the SWMUs presented in the RFI report.

The following recommendations for further action have been developed based on the success of the RFI program in evaluating the risks associated with each SWMU. Table ES-1, which is located at the end of this section, summarizes the risks associated with each SWMU and the recommendations presented.

- **SWMU 17/40**

1) Recommendation: Interim Measures

The human health risk assessment indicates a potential for noncarcinogenic and carcinogenic adverse human health effects for ingestion and dermal contact of surface and subsurface soils and groundwater. The dye tracing study demonstrated a subsurface connection between SWMU 17 and the New River; chemicals of concern found at SWMU 17 were also detected at the discharge point, indicating a release of contaminants. Surface and near surface contamination of soils in areas of active

operations indicates the need for interim measures to control potential threats to the health of site workers.

Interim measures would consist of the implementation of relatively simple engineering controls to prevent or minimize dermal contact with surface soils, including: protective clothing (appropriate gloves and coveralls) and wash stations at easily accessible locations.

2) Recommendation: Conduct Corrective Measures Study (CMS)

A CMS is recommended to address long term solutions to contaminant migration from SWMU 17. Since the active operations represent a continuing source of contamination to the soils and groundwater, corrective measures should be developed which can mitigate contaminant releases while minimizing the impact to the active operations. Such corrective measures might include:

- Construction of a concrete pad with appropriate drainage controls for all burning operations;

- Construction of an impermeable cap to prevent infiltration of precipitation and reduce contaminant flushing; and

- Excavation of the shallow fill materials and installation of an impermeable liner to abate future contaminant migration.

The objective of the CMS is to identify and develop proposed corrective measures and alternatives by screening available technologies, assessing site conditions, and examining financial, institutional, and health impacts. A CMS would justify the recommended corrective actions on a technical, environmental and human health basis, including applicable cleanup levels. The CMS would provide complete information on the status of remediation activities and establish a system for regular reporting, record keeping, and compliance requirements. Finally, the CMS would provide sufficient information so that remedial design and implementation could proceed.

- **SWMU 31**

1) Recommendation: Collect Additional RFI Data

The human health risk assessment indicates a risk based on the hypothetical future site worker groundwater usage scenario. However, migration of metals from the coal ash lagoon sediments to the groundwater and eventually to the New River appears to be occurring. Since the lagoon sediments were only sampled for TCLP waste disposal characterization during the RFI, they could not be considered in the human health risk assessment. Although the previous investigation included sediment sampling data, this information could not be fully assessed for human health risks. Additionally, the compositing procedure used in the previous investigation to collect the samples may not have been appropriate to characterize the sediments. Therefore, additional sampling is recommended to define the nature and extent of contamination at SWMU 31.

Based on the available sampling data, a "No Further Action" recommendation would be inappropriate. However, sampling of the sediments, coupled with the additional sampling of the New River, would allow for risk assessment of the sediment pathway and may provide sufficient information to support a "No Further Action" recommendation. Should the supplemental data demonstrate a significant release of contaminants to the groundwater and the New River, the following action alternatives should be considered:

- Eliminate the discharge of filter backwash and drinking water overflow to the lagoons. The discharge to the lagoons is a flushing mechanism which facilitates the migration of metals from the sediments to the groundwater; and

- Closure of SWMU 31 through excavation of sediments and backfilling of the lagoons.

- **SWMU 48**

1) Recommendation: Perform Dye Tracing Study

Better definition of the groundwater flow at the SWMU 48 area and identification of specific discharge points are necessary to fully evaluate site conditions in this vicinity. Therefore, a dye tracing study is recommended for the SWMU 48 area. The study

would help to define groundwater movement throughout this vicinity, providing useful information for SWMUs 13, 16, 27, 28, 29, 30, 50, 51, 52, 53, and 59.

2) Recommendation: Access Restriction/Surface Water Runoff Drainage Control

Human health risk analysis suggests the potential for carcinogenic adverse human health effects for ingestion and dermal contact with surface soils (the most significant surface soil contamination appears to be from the upper disposal mound). However, the risk analysis determined that the inhalation of particulates pathway is not a concern. Therefore, restriction of access by installing a fence around the upper oily waste disposal mound at this SWMU is recommended to minimize contact with surface soils. Construction of surface water drainage controls will minimize the potential for contaminant migration through runoff.

- **SWMU 54**

1) Recommendation: Conduct Corrective Measures Study (CMS)

Risk analysis indicates the potential for noncarcinogenic and carcinogenic adverse human health effects for dermal and ingestion exposure scenarios for subsurface soils and groundwater. Chemicals of concern identified for SWMU 54 were also found in New River sediments indicating contaminant migration. Additionally, this area is not within the facility security fence and is accessible from the New River. SWMU 54 is also prone to flooding which may transport contaminants to downstream receptors. Therefore, a CMS is recommended to define methods of source remediation.

- **STROUBLES CREEK**

1) Recommendation: Additional Sampling

Risk analysis suggests a low potential for carcinogenic adverse human health effects for dermal and ingestion exposure scenarios for sediments and for dermal exposure scenarios for surface water. However, since contaminants were found in the sample taken upstream of RAAP, and since only two samples were collected, additional work is required to fully characterize the creek. Additional sampling may indicate contaminant

sources unrelated to activities at RAAP. Complete characterization of the creek should include a detailed analysis of the effects of dilution on the contaminants.

- **NEW RIVER**

1) Recommendation: Additional Sampling

Risk analysis suggests the potential for carcinogenic adverse human health effects for dermal and ingestion exposure scenarios for sediments and for dermal exposure scenarios for surface water. However, since sample locations were chosen to correspond to the likely discharge point of the four SWMUs investigated for this report, the possible impacts of other SWMUs or permitted outfall discharges to the river have not been fully explored. Therefore, additional work is necessary to completely characterize the river. Additional sampling may indicate contaminant sources unrelated to activities at RAAP. Complete characterization of the river should include a detailed analysis of the effects of dilution on the contaminants.

TABLE ES-1

SUMMARY OF RFI RECOMMENDATIONS
RADFORD ARMY AMMUNITION PLANT
RADFORD, VIRGINIA

SWMU or Area of Concern	Human Health Risk Concern[1]	Media	Receptor[2]	Exposure Route	Recommendation
SWMU 17/40: Contaminated Waste Burning Areas and Sanitary Landfill	Yes	Groundwater Soil	Site Workers Construction Workers Recreational Users	Dermal Ingestion	Conduct Corrective Measures Study Interim Measures
SWMU 31: Coal Ash Settling Lagoon	Yes	Groundwater	Site Workers	Dermal Ingestion	Collect Additional RFI Data
SWMU 48: Oily Wastewater Disposal Area	Yes	Groundwater Soil	Site Workers Construction Workers Recreational Users	Dermal Ingestion Inhalation	Perform Dye Tracing Study Access Restriction/Surface Water Runoff Drainage Control
SWMU 54: Propellant Ash Disposal Area	Yes	Groundwater Soil	Site Workers Construction Workers	Dermal Ingestion	Conduct Corrective Measures Study
Stroubles Creek	Yes	Surface Water Sediment	Site Workers Recreational Users	Dermal Ingestion	Additional Sampling
New River	Yes	Surface Water Sediment	Site Workers Recreational Users	Dermal Ingestion	Additional Sampling

[1] Risk Criteria Defined in the Baseline Risk Assessment (Section 6)

SECTION 1

INTRODUCTION

1.1 INTRODUCTION

1.1.0.1. This document is the draft report for the Resource Conservation and Recovery Act (RCRA) Facility Investigation (RFI) in support of the Permit for Corrective Action and Incinerator Operation at Radford Army Ammunition Plant (RAAP) located in Radford, Virginia. This report has been prepared for the U.S. Army Environmental Center (USAEC), formerly the U.S. Army Toxic and Hazardous Materials Agency (USATHAMA), and is being submitted under the requirements of Contract No. DAAA15-90-D-0008, Task DA04. The report was prepared by Parsons Engineering Science (Parsons ES), formerly Engineering-Science, Inc.

1.1.0.2. A Permit for Corrective Action and Incinerator Operation (No. VA1-21-002-0730) was issued to Hercules Incorporated by the U.S. Environmental Protection Agency (USEPA), under the authority of the Solid Waste Disposal Act, as amended by RCRA (1976), and the Hazardous and Solid Waste Amendments (HSWA) of 1984. RAAP, which is currently operated by Alliant Techsystems, Inc., is owned by the U.S. Army. The RCRA permit allows Alliant Techsystems to operate a hazardous waste treatment, storage, and disposal facility in Radford, Virginia. The full RCRA permit comprises USEPA's portion, which addresses provisions of HSWA, and the Virginia Department of Environmental Quality portion, which addresses the provisions of RCRA for which the Commonwealth of Virginia is authorized. Corrective action is addressed by HSWA and enforced by USEPA. Section 3004(u) of RCRA (Section 206 of HSWA requires corrective action as necessary to protect human health and the environment from releases of hazardous waste constituents from any solid waste management unit (SWMU). The corrective action permit includes requirements for RAAP to conduct verification investigations (VIs) at sites of suspected contamination, RFIs at sites of known contamination, and Corrective Measures Studies (CMSs) at sites requiring remediation.

1.1.0.3. In 1992, RAAP completed several VIs and RFIs at selected SWMUs throughout the installation. Results of those studies were presented in the Draft RFI Report

(Dames & Moore, 1992a) and the Draft VI Report (Dames & Moore, 1992b). Parsons ES was tasked to conduct further investigations at SWMUs 17, 40, 31, 48, and 54, based upon recommendations made in those reports. The recommendations included:

- SWMU 17-Contaminated Waste Burning Areas: Based on the RFI, additional characterization of hydrogeologic conditions, utilizing a dye-tracer study, was required as well as a sampling program for groundwater discharge points.
- SWMU 40-Sanitary Landfill (Nitroglycerin Area): The VI conducted in this area concluded that groundwater sampling should be performed and that the dye tracer study for SWMU 17 include this adjacent area.
- SWMU 31-Coal Ash Settling Lagoons: The Waste Characterization Study conducted at this site concluded that a groundwater investigation was needed.
- SWMU 48-Oily Wastewater Disposal Area: The VI report recommended that future activities include groundwater and soils investigations to determine the source and extent of fuel contamination.
- SWMU 54-Propellant Ash Disposal Area: An RFI/CMS was recommended in the VI report.

This report presents the results of these investigations.

1.2 PROJECT OBJECTIVES

1.2.0.1. The objectives of the RFI, as specified in the permit, are to: characterize the nature, extent, concentration and rate of migration of releases of hazardous waste or hazardous constituents from the SWMUs into groundwater, surface water, soil, or any other identified media; identify and evaluate potential impacts to human and environmental receptors; provide a detailed geologic and hydrogeologic characterization of the area surrounding and underlying the SWMUs; and determine the need for and scope of corrective measures.

1.2.0.2. The objectives were accomplished by performing the investigation field tasks and data analysis in accordance with the RFI Work Plan (Engineering-Science, Inc.,

1994a) and the RCRA Corrective Action Program Guide-Interim (U.S. Department of Energy, May 1993).

1.3 SCOPE OF WORK

1.3.0.1. The RFI scope of work included the following field tasks.

SWMU 17/40-Contaminated Waste Burning Areas and Sanitary Landfill (SWMUs were combined because of proximity and similar subsurface conditions):

- A dye trace study test was performed preliminary to the other characterization activities to provide an understanding of groundwater movement in karstic environments. The final report was submitted by Parsons ES to the USEPA in March 1994 (amended in September 1994);
- Seven soil borings were installed;
- Three surface soil samples were collected;
- Four groundwater samples were collected - two monitoring wells were dry; and
- The discharge point at the New River was sampled.

SWMU 31-Coal Ash Settling Lagoons:

- Four groundwater monitoring wells were installed;
- Four groundwater samples were collected;
- Aquifer testing (slug tests) was conducted on each new well;
- Six lagoon sediment samples were collected; and
- Staff gauges (water elevations) were installed in the lagoons and river.

SWMU 48-Oily Wastewater Disposal Area:

- Four groundwater monitoring wells were installed;
- Four groundwater samples were collected;
- Three aquifer slug tests were conducted;
- Two soil borings were installed; and

- Six surface soil samples were collected.

SWMU 54-Propellant Ash Disposal Area:

- Two waste composite samples were collected;
- 16 soil borings were installed; and
- Three groundwater samples were collected.

Other non SWMU-specific field activities were completed based on identified deficiencies in the existing characterization information. These activities included:

- Two sediment and surface water samples were collected from Stroubles Creek;
- Six sediment and surface water samples were collected from the New River; and
- 18 soil borings (36 soil samples) were installed in background areas to establish background metals concentrations.

These field tasks were conducted during December 1994/January 1995, and July 1995.

1.4 REPORT ORGANIZATION

1.4.0.1. This report consists of fourteen sections and nine supporting appendices. The report is Volume I. The Appendices are contained in Volume II. Section 1 provides an introduction and statement of the project objectives. A detailed description of the current conditions at RAAP, including facility background and summary of previous investigations is presented in Section 2. Section 3 describes the environmental setting including the results of a geological structural study performed by Parsons ES. Section 4 outlines the procedural aspects of the field investigation program.

1.4.0.2. Section 5 discusses data management and data quality issues, including entry of all data into the USAEC's Installation Restoration Data Management Information System (IRDMIS) database, while Section 6 presents a baseline risk assessment. Sections 7 through 12 present the site characterization of the four SWMUs, Stroubles Creek and the New River. Section 13 presents conclusions and recommendations. References can be found in Section 14.

1.4.0.3. A listing of acronyms and abbreviations used throughout the report is included as Appendix A and is also presented after the Table of Contents. Other appendices contain the detailed information from the field tasks (drilling logs, aquifer testing, etc.) and analytical data (data summary tables, risk tables, etc.). Oversized maps are presented as Plates 1, 2, and 3.

SECTION 2

FACILITY DESCRIPTION

The background information in this section has been adapted from previous RFI and Vl reports prepared for the USAEC (Dames & Moore, 1992a and 1992b).

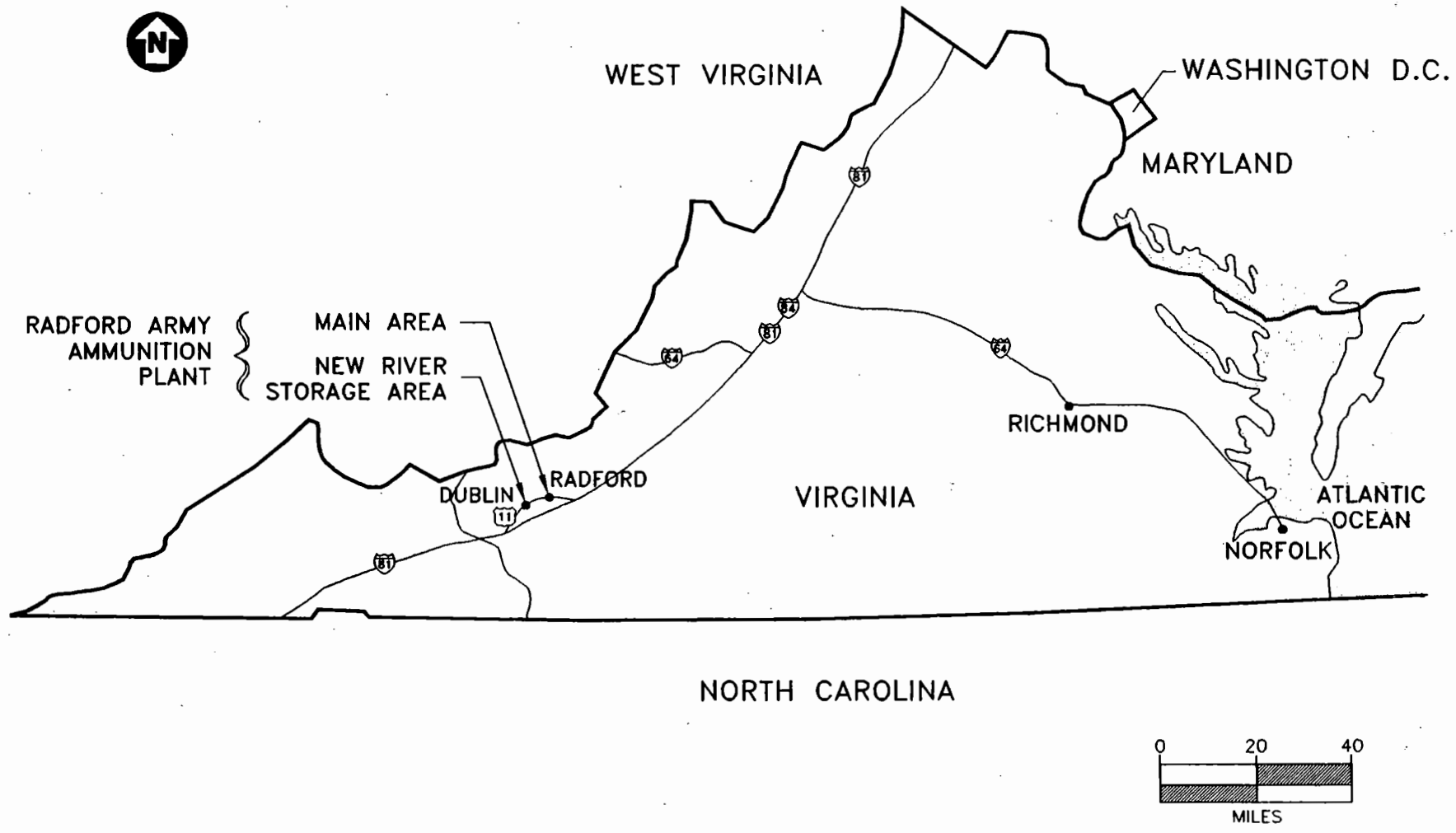
2.1 FACILITY LOCATION

2.1.0.1. RAAP is located in the mountainous region of southwestern Virginia (Figure 2.1) in Pulaski and Montgomery Counties. These two counties along with Floyd and Giles Counties make up the New River Valley Planning District Commission. The installation consists of two noncontiguous areas - the Radford Unit (or Main Section) and the New River Ammunition Storage Area Unit. The Main Section is located approximately 4 miles northeast of the city of Radford, Virginia, approximately 10 miles west of Blacksburg, Virginia, and 47 miles southwest of Roanoke, Virginia. The New River Unit is located about 6 miles west of the Main Section, near the town of Dublin, Virginia, (Figure 2.2). The Main Section of RAAP (Figure 2.3) is the focus of this report; all uses of the terms "RAAP," "the facility," or "the installation" in this report refer to the Main Section only.

2.1.0.2. RAAP lies in one of a series of narrow valleys typical of the Appalachian Mountain region. This valley is oriented in a northeast-southwest direction, and is approximately 25 miles long, 8 miles wide at the southwest end, narrowing to 2 miles at its northeast end. The facility is situated along the New River in the relatively narrow northeast region of the valley.

2.1.0.3. RAAP is divided into two areas (northern and southern) by the New River. The northern half or "Horseshoe Area" is located within the New River meander. Located in the Horseshoe Area are the Nitroglycerin (NG) No. 2 Area, the Cast Propellant Area, and the Continuous Solvent Propellant Area. Many landfills at RAAP are located in this area, including the Hazardous Waste Landfill, the currently active Sanitary Landfill, and the Waste Propellant Burning Ground. Three of the SWMUs discussed in this report are located in this

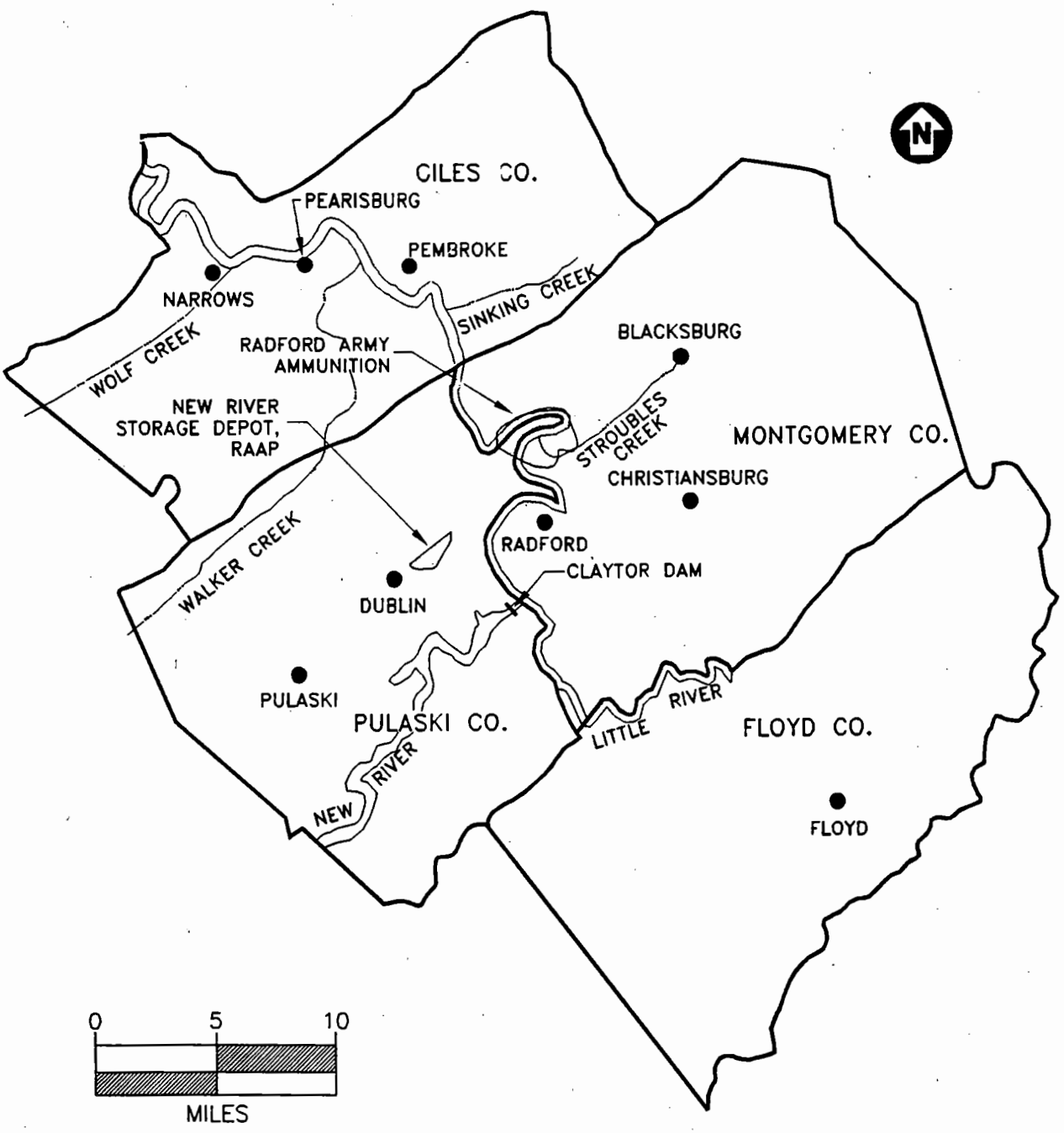
FIGURE 2.1
LOCATION MAP
RADFORD ARMY AMMUNITION PLANT
RADFORD, VIRGINIA



SOURCE: USAEHA, 1980, AS CITED IN DAMES & MOORE, 1992

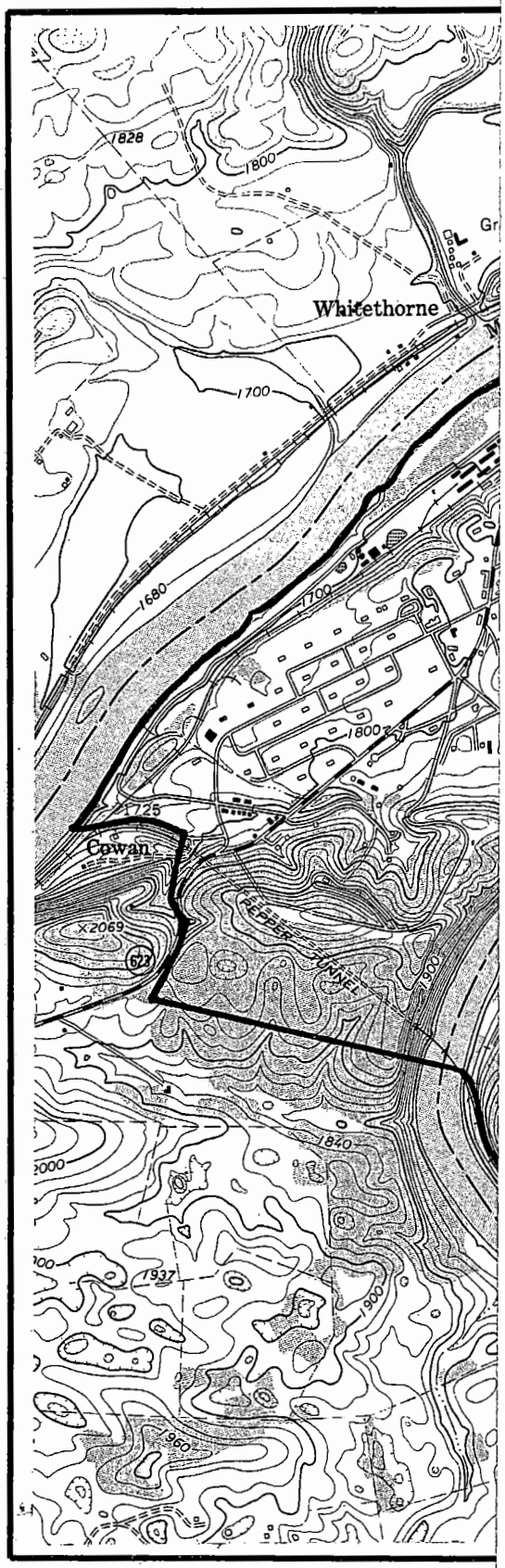
FB517001

FIGURE 2.2
RAAP AND VICINITY MAP
RADFORD ARMY AMMUNITION PLANT
RADFORD, VIRGINIA



SOURCE: USAEHA, 1980, AS CITED IN DAMES & MOORE, 1992

FB517002



0 2,000 4,000

FEET

SCALE = 1:24,000

LEGEND

PROPERTY LINE

SOURCE: U.S. GEOLOGICAL SURVEY, RADFORD NORTH QUADRANGLE

area, including SWMU 31 (Coal Ash Settling Lagoons), SWMU 48 (Oily Wastewater Disposal Area), and SWMU 54 (Propellant Ash Disposal Area). South of the New River is the "Main Manufacturing Area," which includes the Finishing Area; the TNT Area; the NG area; Nitrocellulose (NC) and Acid Areas; the Automated Propellant Area; and the Administration Area. Two SWMUs discussed in the report, SWMU 17 (Contaminated Waste Burning Areas) and SWMU 40 (Sanitary Landfill), as well as Stroubles Creek, are located in this area. Plate 1 presents a topographic and SWMU location map for the entire facility; the map includes all SWMUs including those which were not the subject of this investigation.

2.2 FACILITY HISTORY

2.2.0.1. RAAP is a government-owned, contractor-operated (GOCO) military industrial installation supplying solvent and solventless propellant grains and trinitrotoluene (TNT) explosives. From its inception as a GOCO facility in 1940 until 1995, RAAP had been operated by Hercules Incorporated. On March 16, 1995, Alliant Techsystems, Inc. bought out Hercules, Inc. and took over the operation of RAAP.

2.2.0.2. Construction of the RAAP production facility began in 1940 with the impending participation of the United States in World War II, and the determination by Congress of a need for increased ammunition production facilities. Initially, RAAP consisted of two distinct areas - a smokeless-powder plant (Radford Ordnance Works [ROW]) and a bag-manufacturing and loading plant for artillery, cannon, and mortar projectiles (New River Ordnance Works [NROW]). These two production facilities were operated separately from 1940 to 1945. Late in 1945, ROW was designated as the Radford Arsenal, and NROW was designated as a subpost. By January 1950, NROW was made an integral part of the Radford Arsenal and no longer considered a subpost. The arsenal was renamed Radford Ordnance Plant in 1961 and was finally redesignated as the RAAP in August 1963 (USATHAMA, 1984).

2.2.0.3. Expansion of both ROW and NROW continued throughout World War II. Late in 1945, the Radford Unit was placed on standby status. The following year, the nitric acid area of the plant was reactivated to produce ammonium nitrate fertilizer, an activity that continued until 1949 under contract with Hercules Powder Company (later Hercules

Incorporated). In September 1945, the NROW was declared surplus; but in April 1946, the magazine areas were changed from surplus to standby status. Between December 1946 and January 1948, large parcels of the NROW plant manufacturing area were sold (USATHAMA, 1984). These parcels were excess land holdings that had never been used for production purposes.

2.2.0.4. Between 1952 and 1958, Goodyear Aircraft Corporation, of Akron, Ohio, was contracted to manufacture component parts used in missile production at RAAP. The close coordination required between Goodyear and Hercules resulted in Goodyear moving its assembly and coating operations to RAAP. In 1958, Hercules took over the Goodyear operations at this plant (USATHAMA, 1984).

2.2.0.5. In mid-1968, the continuous TNT plant was put into production and remained in operation until destroyed by an explosion in May 1974. This plant had five main operational areas: the nitration lines, the finishing buildings, the red water concentration facility, the acid neutralization facility, and the spent acid recovery plant. The C-line in the TNT area ran from 1983 to 1986, when the TNT plant was placed on standby. Later, in December 1988, a facility cleanup was conducted and the plant was prepared for long-term standby status. Between 1990 and 1992 two nitroglycerin facilities went on line at RAAP. Although there was an explosion at one of these in 1993, they both remain active. A chronological listing of major RAAP activities is presented in Table 2.1.

2.3 FACILITY RESPONSIBILITY

2.3.0.1. Based on discussions with plant personnel (1995), the general responsibilities assigned to RAAP have not changed from those outlined by USATHAMA (1976), these include:

- Manufacture of explosives and propellants;
- Handling and storage of strategic and critical materials as directed for other government agencies;

TABLE 2.1

CHRONOLOGICAL LIST OF MAJOR ACTIVITIES AT RAAP

DATE	ACTIVITY
August 1940	Contract signed with Hercules Powder Company for Construction and Operation of smokeless powder plant
September 1940	Construction of Radford Plant
April 1941	Production started at Radford Plant
1941	Separate New River bag loading plant constructed
1941/45	Construction of various facilities continued
1945	Consolidation of Radford and New River plants
1945	Production stopped-plant in standby
1946-49	Ammonium nitrate produced in Acid Area
1949	Limited resumption of powder production
1950	Plant reactivated for Korean Conflict
1950/51	Large areas of plant rehabilitated
1951	Multibase propellant and cast rocket grain facilities constructed
1967/68	Continuous TNT lines constructed
1970/72	New acid plants constructed
1971	Preproduction project work on Continuous Automated Multibase Line (CAMBL) started
1972	Continuous Automated Single-Base Line (CASBL) construction started
1972	Continuous nitrocellulose nitration construction started
1973	Military Construction, Army (MCA) pollution abatement facilities construction started
May 1974	TNT plant explosion
1976	Continuous Automated Single-Base Line M6/M1 conversion started
1978	Construction started on biological wastewater treatment plant
1980	C-line Nitrocellulose Manufacturing Area closed
1983	TNT plant reopened
1986	TNT plant placed on standby
1987	C-line Nitrocellulose Manufacturing Area reopened
December 1988	TNT plant cleanup, preparation for long-term standby
1990	Nitroglycerin facility went on line
November 1992	Pollution control system upgrade completed for explosive waste incinerators
1992	Second nitroglycerin facility went on line
January 1993	Upgrade to biological wastewater treatment plant began
1993	Explosion at nitroglycerin facility
October 1994	Operating permit approved for explosive waste incinerators
March 1995	Alliant Techsystems, Inc. buyout of Hercules complete

Source: Modified from USATHAMA, 1976

- Operation and maintenance, as directed, of active facilities in support of current operations. Maintenance and/or lay-away, in accordance with Ammunition Procurement and Supply Agency instructions, of standby facilities, including any machinery and packaged lines received from industry,in such conditions as will permit rehabilitation and resumption of production within the time limitations prescribed;
- Receipt, surveillance, maintenance, renovation, demilitarization, salvage, storage, and issue of assigned Field Service Stock and industrial stock as required or directed;
- Procurement, receipt, storage, and issue of necessary supplies, equipment, components, and essential materials;
- Mobilization planning, including review and revision of plant as required;
- Custodial maintenance and administrative functions of subinstallations; and
- Support services for tenants.

2.3.0.2. These responsibilities are met through the efforts of the operating contractor, Alliant Techsystems, Inc. The Administrative Contracting Officer (ACO) and his staff provide technical assistance and administer the contracts with the civilian operating contractors. RAAP provides logistics support for tenant activities such as the U.S. Army Research, Development and Acquisition Information Systems Agency, which is charged with performing data processing activities during peacetime.

2.4 INDUSTRIAL OPERATIONS

2.4.0.1. From 1941 to the present the principal end products produced at RAAP have been TNT, single-base and multi-base propellants, and cast and solventless propellants. Intermediate products produced are oleum (concentrated sulfuric acid), nitric acid, NG, and NC.

2.4.0.2. Production at RAAP is accomplished at the primary and secondary manufacturing areas. The primary manufacturing processes are the production of single-base and multi-base solvent propellants, cast and solventless propellants, and TNT. Separate process areas are provided for the production of solventless propellant, referred to as rolled powder. The process steps are essentially the same for the production of solvent-type

single-, double-, and triple-base propellants; the major differences are in the specific chemical and explosive ingredients added. Single-base and double-base propellants may include one or more of the following chemicals: barium nitrate, potassium nitrate, ethyl centralite, graphite, carbon black, potassium sulfate, lead carbonate, dibutylphthalate, and diphenylamine. Triple-base propellants consist of ethyl centralite and potassium sulfate cryolite, while special high-energy propellants contain high melting point explosives (HMXs). The secondary manufacturing processes include the production of oleum, nitric acid, NG, and NC.

2.4.1 Propellant Production

2.4.1.1. The separate processes used in the production of the various propellants are discussed below.

- Single-base solvent propellant - In this batch process, nitrocellulose is dehydrated and mixed with appropriate chemicals and solvents for the desired blend. The mixture then undergoes a series of operations where it is shaped into a cylindrical block, extruded into strands, and cut to desired size. The solvents ethyl alcohol and ethyl ether are recovered, and the grains are water and air dried. The last major operation includes glazing, blending, and packaging.
- Multibase solvent propellant - The manufacture of the multibase solvent propellant is similar to the single base except for the addition of nitroglycerin, nitroguanidine, and other chemicals for the formulation desired. The ethyl alcohol and acetone solvents are recovered, and the mix is forced-air dried.
- Cast propellant - The manufacturing of cast propellants for rocket grains requires the mixing of nitroglycerin with triacetin, diethyl phthalate, ethyl centralite and 2-nitrodiphenylamine (2-NDPA) (depending on formulation), and a casting solvent, followed by the addition of the base grain. The rocket grain is then cast, cured, machined, assembled, and packaged.
- Solventless propellant (rolled powder) - The solventless propellant is prepared by a batch process in which nitrocellulose, nitroglycerin, and other chemicals are slurried in water, wrung to a wet cake, and dried to a paste. After the paste is blended, the mixture is rolled into sheets. The propellant is then

wound into a carpet roll for extrusion into small rocket grains. The propellant is also rolled and finished for mortar increments.

2.4.2 TNT Production

2.4.2.1. Before its destruction in May 1974, the TNT plant consisted of three manufacturing lines (A, B, and C), each with a rated capacity of 50 tons/day using the modern Canadian Industries, Limited (CIL), continuous nitration and purification process and an advanced drying, solidifying, and packaging operation. When the TNT plant reopened in 1983, the B and C lines were restored, and improved safety equipment, process equipment, and a TNT wastewater treatment facility were added. The overall volume of TNT production was reduced. Operations for fume recovery, red water concentration and destruction, waste neutralization, and spent acid recovery were located in the TNT plant area. These operations directly support the manufacture of TNT.

2.4.2.2. In the nitration process, a toluene feed stock was reacted with a mixture of nitric acid and oleum to yield a crude trinitrotoluene by using eight nitrators and eight separators connected in series for the three nitrating steps (mono, di, and tri). The crude TNT then flowed to adjacent, series-connected tanks located in the same building. The steps in the purification process involved an acid wash and two sellite (sodium sulfite) wash operations. A yellow water produced in the acid wash step was normally fed back into the No. 2 (di-) nitrator in the nitration process. The unwanted isomers removed in sellite washing produced a red water waste.

2.4.2.3. After purification, the molten TNT was mixed with water and the slurry was pumped to the finishing building. The water was then separated from the TNT and recycled to the purification process. The TNT was passed through a holding tank, then dried and flaked for packaging into cardboard cartons to a net weight of 50 pounds.

2.4.2.4. Nitrogen oxide fumes generated during nitration were exhausted and scrubbed in the fume recovery towers for recovery of the oxides as nitric acid for reuse in the process. The red water generated in the sellite TNT purification process has been disposed of by various means, including incineration in rotary kilns or sale to the paper industry. Incineration ash has been landfilled in various RAAP locations. Acid waste was

processed through three tanks wherein the pH level was adjusted by the addition of soda ash (sodium carbonate). The treated effluent was then diluted with TNT Area cooling water and released to Stroubles Creek. The spent acid from the nitration process was separated by distillation into nitric acid, which was reused, and into sulfuric acid, which was concentrated at another part of the plant and sold.

2.4.3 Secondary Manufacturing Operations

2.4.3.1. The secondary manufacturing operations at RAAP are the production of oleum, sulfuric and nitric acids, nitroglycerin, and nitrocellulose, as described below:

- Oleum 40 percent is manufactured by absorbing sulfur trioxide (SO_3) in 100 percent sulfuric acid. A new plant, constructed in 1970, uses a sulfur acid regeneration (SAR) process.
- The ammonia oxidation process (AOP) is used to make weak, 60 percent nitric acid. A new plant was constructed in 1970.
- The sulfuric acid concentration (SAC) process produces 93 percent sulfuric acid, and concentrates the sulfuric acid residue from the nitric acid concentration (NAC) and TNT processes. This process was replaced by the SAR process in 1970.
- The NAC process is used to concentrate the weak nitric acid produced in the AOP plant and to recover the spent acids from the manufacture of NC and NG. This was replaced by a new facility constructed in 1970.

2.4.3.2. NG was manufactured at RAAP by both the batch and continuous (Biazzi) processes. The batch process employed three steps: nitration of glycerin to produce NG, separation, and neutralization of the NG charge. The continuous process is a fully automated controlled method in which the NG is produced by reactions similar to the batch process. In 1984, the batch process became inoperative and was replaced by a continuous process. Since 1984, only the continuous process has been operating.

2.4.3.3. The manufacture of NC starts with the preparation and air drying of cotton linters and wood pulp fibers and the preparation of mixed acid (nitric/sulfuric acid). The remaining major steps consist of nitration and purification. A dry charge of cotton linters or

wood pulp fibers, depending on the type and grade of NC desired, is agitated with the mixed acid in a dipping pot. After nitration, the spent acid is separated from the NC. The raw NC from the nitration operation is stabilized by a stabilization acid boil and two neutral boils in the boiling tub house. It is then transferred to the beater house, where it is cut to suitable size and partially neutralized. Next, in the poacher house, a series of NC boils are performed; first, a soda boil neutralizes any remaining acid, then neutral boils and washes are performed to remove the soda. The NC is then screened, filtered, and washed. In the blender house, NC of various classes is mixed to produce the mixture or blend desired. The mixture is then wrung through centrifugal wringers in the final wringer house to obtain a product containing a small and uniform amount of moisture. The NC is then shipped to the green powder lines for processing into single-base solvent propellant and to the NG premix area for processing into multibase solvent and solventless propellant.

2.5 SUMMARY OF PREVIOUS INVESTIGATIONS

2.5.0.1. Various areas of RAAP have been the subject of numerous environmental investigations by government organizations and private contractors. The earliest extensive environmental studies were conducted in the early- to mid-1980's by the U.S. Army Environmental Hygiene Agency (USAEHA) and the U.S. Army Toxic and Hazardous Materials Agency (USATHAMA). USATHAMA is now known as the U.S. Army Environmental Center (USAEC). These investigations ranged in scope from site specific soil sampling studies (USAEHA, 1987), to large scale pollution abatement studies involving the installation and sampling of numerous groundwater monitoring wells (USAEHA, 1981).

2.5.0.2. As a result of a RCRA Facility Assessment conducted at RAAP (USEPA, 1987), several SWMUs were identified as having the potential for releasing contaminants into the environment. RAAP was issued a RCRA Permit for Corrective Action and Incinerator Operation by the USEPA effective December 13, 1989. As a requirement of this permit, RAAP was tasked to conduct Verification Investigations (VIs) at sites of suspected contamination, RCRA Facility Investigations (RFIs) at sites of known contamination, and Corrective Measures Studies (CMSs) at sites requiring remediation. In 1992, RAAP completed VIs for 36 solid waste management units (SWMUs) (Dames and Moore, Inc. 1992a) and RFIs for 6 SWMUs (Dames and Moore, Inc. 1992b).

2.5.0.3. A dye-trace study was conducted (spring 1994) to better identify groundwater flow paths through the karst limestone in the south-central section of the main manufacturing area (Engineering-Science, 1994b). The results of this study were used to develop the Work Plan for the RFI of SWMUs 17 and 40 (Engineering-Science, 1994a).

2.5.0.4. As a result of the findings of VIs conducted at SWMUs 17/40, 31, 48, and 54, which identified releases of contamination, Parsons ES performed RFIs on these SWMUs in December 1994 through July 1995. Those findings are presented in this report.

SECTION 3

ENVIRONMENTAL SETTING

3.1 CLIMATE

3.1.0.1. The climate of the area encompassing RAAP is classified as "moderate continental." This climate is characterized by moderately mild winters and warm summers. The prevailing winds are from the southwest, with a northerly component during the cold season. The average yearly windspeed is 8 miles per hour [NRVPDC, 1994; Dames & Moore, Inc., 1992(a)].

3.1.0.2. Tables 3.1 and 3.2 list the average monthly precipitation and temperature from four weather stations in the vicinity of RAAP. The average monthly temperature ranges from 29.6°F in January to 72°F in July, with an annual average temperature of about 52°F. Average monthly precipitation ranges from about 2.5" to 4.0" with an annual total precipitation between 36.9" and 41.5" (Virginia State Climatological Office, 1995). Class A pan evaporation was measured in the Roanoke, Virginia, area at 43" per year. Lake evaporation was measured at 32" per year in the same area. Potential evapotranspiration has been calculated at 30" per year using the Thornthwaite method (Virginia State Climatological Office, 1995). Based on these data, the net precipitation in the vicinity of RAAP ranges between 6.9" and 11.5" annually. Snowfall in the vicinity of RAAP averages 17" annually. Montgomery and Pulaski Counties lie in one of the areas of highest occurrence of dense fog in the United States. Dense fog can be expected to occur between 20 and 45 days per year.

3.2 PHYSIOGRAPHY

3.2.0.1. RAAP lies within the Valley and Ridge province of the Appalachian physiographic division. The Valley and Ridge province is characterized by a series of long, narrow, flat-topped mountain ridges separated by valleys of varying widths. Either of these landforms may predominate; the mountains may be widely spaced and isolated or so closely spaced that the lowlands are disconnected or absent. A distinctive feature of the installation area is the absence of mountain ridges.

TABLE 3.1

AVERAGE MONTHLY PRECIPITATION (1961-1990) FOR LOCATIONS NEAR RAAP

Station	Location		Annual Precipitation (Inches)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
	Latitude	Longitude													
Blacksburg	37°11'N	80°25'W	40.91	2.76	2.89	3.56	3.62	4.04	3.41	4.01	3.77	3.51	3.63	2.89	2.82
Pulaski	37°03'N	80°45'W	36.93	2.28	2.66	3.05	2.84	3.81	3.45	3.92	3.29	2.99	3.34	2.57	2.73
Staffordsville	37°16'N	80°43'W	37.54	2.53	2.73	3.12	3.31	3.66	3.21	3.95	3.50	3.17	3.12	2.67	2.57
Floyd	37°56'N	77°27'W	41.45	2.67	2.97	3.68	3.58	3.94	3.34	3.85	3.40	3.83	4.01	3.48	2.70

Source: Virginia State Climatological Office, 1995

TABLE 3.2

AVERAGE MONTHLY TEMPERATURES (1961-1990) FOR LOCATIONS NEAR RAAP

Station	Location		Average Annual												
	Latitude	Longitude	Temp (°F)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Blacksburg	37°11'N	80°25'W	51.0	29.6	32.4	41.8	50.5	59.2	66.8	70.6	69.6	63.1	51.9	43.2	33.8
Pulaski	37°03'N	80°45'W	51.9	31.0	33.4	42.4	50.9	60.3	67.7	71.3	70.2	63.7	53.0	43.7	35.3
Staffordsville	37°16'N	80°43'W	53.1	32.1	35.3	45.1	53.3	61.1	68.0	72.0	70.8	64.6	53.7	44.9	36.4
Floyd	37°56'N	77°27'W	51.3	31.3	34.2	42.8	50.9	59.1	66.0	69.6	68.6	62.5	52.0	43.2	34.8

Source: Virginia State Climatological Office, 1995

3.2.0.2. The topography within the installation varies from a relatively flat floodplain to elevated uplands in the extreme southeast section (Figure 2.3). The New River forms the RAAP boundary on the north, with the elevation approximately 1,675 feet above mean seal level (msl). The eastern boundary represents a transition from floodplain elevation (1,680 feet msl) to an elevation of 1,900 feet msl in the upland. The southern boundary traverses terrain consisting of creek bottoms and sharply rising summits. The western boundary follows the bluff line overlooking the New River to a point where the Norfolk and Southern Railroad crosses the lower arm of the Horseshoe Area. This facility displays an overall relief of 342 feet. In the Horseshoe Area to the north and east, the New River has a narrow floodplain. Just west of the Waste Propellant Burning Ground, the floodplain is terminated by steep bluffs that extend westward to the plant boundary. The Horseshoe Area exhibits rolling karst terrain, with three prominent terraces and escarpments that are remnants of ancient New River floodplains.

3.2.0.3. RAAP contains prominent karstic features including sinkholes, caves and caverns. Karst landforms occur in carbonate rock formations as the result of the dissolution of rock by naturally occurring carbonic acid in rainwater. As the rock is dissolved, cavities or caverns are formed beneath the earth's surface. Occasionally, large caverns collapse producing a depression or sinkhole on the surface. Numerous sinkholes are apparent along the western and southern boundaries of the facility.

3.3 LAND USE/DEMOGRAPHICS

3.3.0.1. Because of the steep terrain, the area surrounding RAAP has not been highly developed. Land use in the vicinity of RAAP has been mostly rural; the less rugged areas are primarily used for agriculture. The Jefferson National Forest is located approximately two miles north of the facility. The majority of land in the New River Valley, which includes Montgomery, Pulaski, Giles, and Floyd Counties as well as the city of Radford, is forested. Only 38 percent of the area of the New River Valley is classified as nonforest land, including agricultural land, developed land, and water acreage (NRVPDC, 1994). The Blacksburg, Christiansburg VPI Water Authority owns four parcels of land adjacent to RAAP. There are approximately 200 private residences located adjacent to RAAP (Dames & Moore, 1992b). The largest substantial development, Fairlawn, is located about two miles southwest of the facility boundary. The city of Radford, with a population of 15,940 in 1990, is located about four miles southwest of the facility. Urbanization greatly

influences the population density in the vicinity of RAAP. The city of Radford has 1,626 persons per square mile, while Montgomery and Pulaski Counties have population densities of 190 and 108 persons per square mile, respectively (NRVPDC, 1994).

3.3.0.2. Between 1960 and 1980, Montgomery and Pulaski Counties experienced strong population growth. Montgomery County continues to show the strongest population growth in the New River Valley. Population projections indicate a general decrease in population growth rate for the New River Valley through 2010 (Table 3.3). The median age within individual jurisdictions in the New River Valley varies between 22 years old for the city of Radford, to 38.1 years old for Giles County. The median age for Montgomery County (25.6 years old) and the city of Radford is lowered by the concentration of college students in these jurisdictions.

3.4 REGIONAL SOILS

3.4.0.1. RAAP is underlain by 10 predominant soil types as mapped by the Soil Conservation Service (SCS, 1985a; 1985b). The identified SCS soil types are discussed in detail in the following subsections. Site specific information concerning soil types was obtained from a soil background metals study completed for the RFI. The study, which is described in Subsection 4.4, was undertaken to derive background concentrations of metals in unimpacted site soils. Background soils were collected to reproduce the soil types and depths sampled during previous investigations to allow valid comparisons between naturally occurring background metals and concentrations in soils from any SWMU. A review of previous sampling investigations revealed that only three soil types covered all the areas of concern across the site. Therefore, only the Wheeling Sandy Loam, the Braddock Loam, and the Unison-Urban Land Complex soils were sampled for the background study. Figure 3.1 presents the SCS soil types covering the facility, the relative SWMU locations, and the background sampling locations.

3.4.1 Soil Type 1: Fluvaquents

3.4.1.1. Fluvaquents consist of soils on long-narrow floodplains. The soils are more than 60 inches deep to bedrock and have a seasonal high water table at or near the surface. Slopes range from 0 to 2 percent. The soil is unconsolidated, stratified alluvium with varied

TABLE 3.3

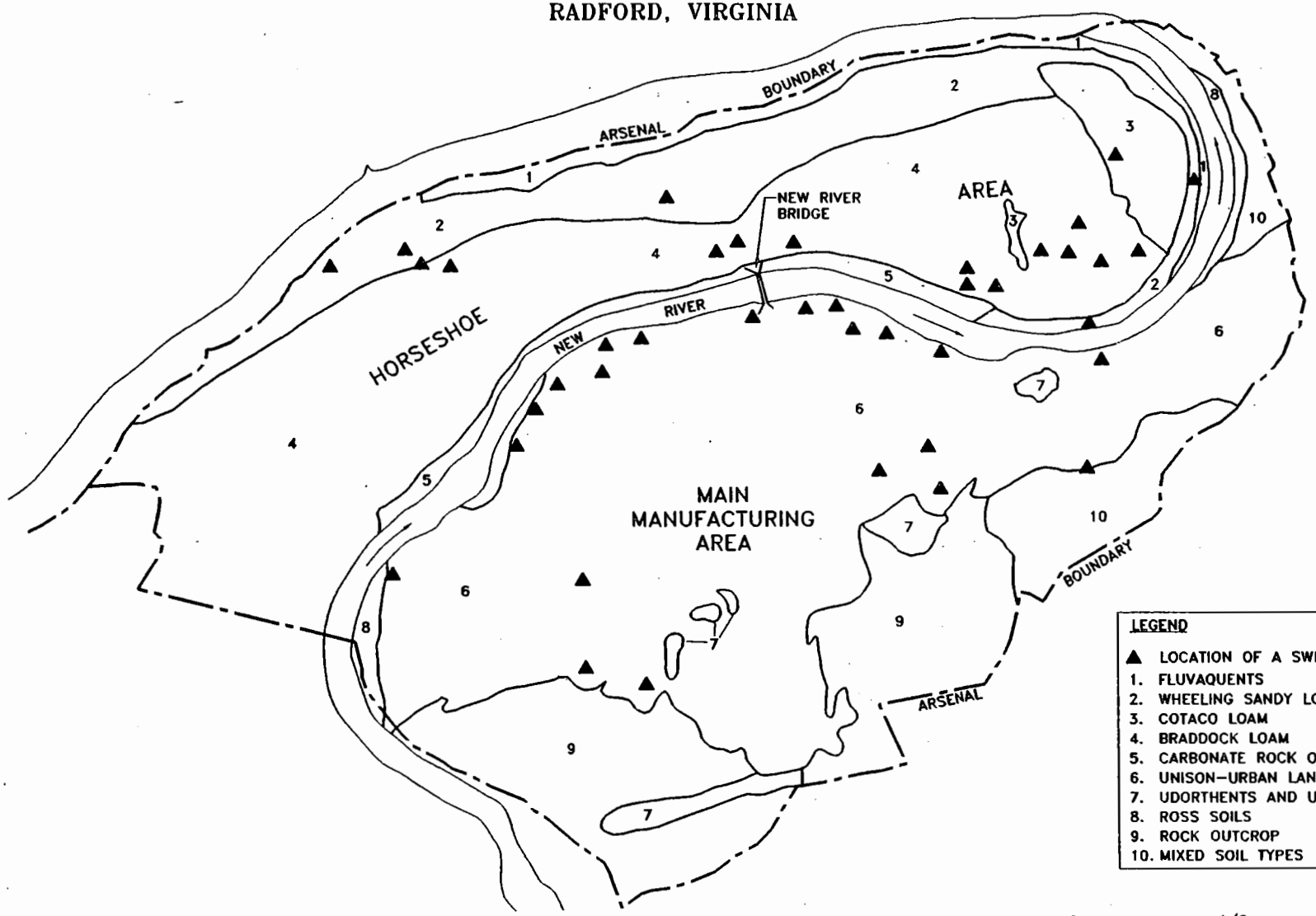
POPULATION IN VICINITY OF RAAP

Jurisdiction	1980	Percent Change (1970-1980)	1990	Percent Change (1980-1990)	2000[a]	Percent Change[a] (1990-2000)	2010[a]	Percent Change[a] (2000-2010)
Montgomery Co	63,516	34.7	73,913	16.4	79,604	7.7	83,915	5.4
Pulaski Co	35,229	19.2	34,496	-2.1	34,206	-0.8	34,198	0.0
City of Radford	13,225	14.0	15,940	20.5	17,203	7.9	17,999	4.6
Floyd Co	11,563	18.3	12,005	1.0	12,459	3.8	12,898	3.5
Giles Co	16,741	6.4	16,366	-1.0	16,121	-1.5	16,042	-0.5

[a] Projected

Source: Virginia Population Projections, 1993

FIGURE 3.1
SOIL TYPES AND SWMU LOCATION MAP
RADFORD ARMY AMMUNITION PLANT
RADFORD, VIRGINIA



BASE MAP SOURCE: USATHAMA 1976, AS CITED IN DAMES & MOORE, 1992
SOIL DATA SOURCE: SOIL CONSERVATION SERVICE, SOIL SURVEY OF MONTGOMERY CO., VA (1985) AND PULASKI CO., VA (1985).

517F02-3 9/11/95

texture typically including layers of gravel. At RAAP, this soil type is found in a narrow strip along the floodplain at the northern boundary of the Horseshoe Area.

3.4.1.2. The surface of this soil type is often strewn with debris deposited during flooding. Reaction, permeability, available water capacity, natural fertility, organic matter content, and other chemical and physical properties are variable in this soil type.

3.4.2 Soil Type 2: Wheeling Sandy Loam

3.4.2.1. The Wheeling Sandy Loam soil is level to nearly level (slopes ranging from 0 to 2 percent) and is at least 60 inches deep to bedrock. The seasonal high water table is not within six feet of the surface. Typically, the surface layer is a 10-inch-thick, dark-brown-sandy loam underlain by a 42-inch-thick subsoil. The upper 23 inches of the subsoil is dark brown sandy clay loam, and the lower 19 inches is dark brown sandy loam. The substratum is dark brown gravely sandy loam to a depth of 60 inches or more. This soil type comprises about 25 percent of the upland regions of the Horseshoe Area at RAAP.

3.4.2.2. The permeability and available water capacity of the Wheeling soil is moderate; surface runoff is slow. The soil is medium in natural fertilizer, moderately low in organic matter content, and moderately to strongly acidic. The hazard of erosion is slight. The Wheeling soil is prime farmland and is very well suited to cultivating crops.

3.4.2.3. During the soil background metals study, these soils were sampled throughout the Horseshoe Area. The lithology of the upper 60 inches of the background soil samples generally corresponded with the description of the Wheeling Sandy Loam as given above. At greater than 60 inches in depth, the soils are predominantly a mixture of silt and sand, with minor amounts of clay. SWMU 31 and SWMU 54 are underlain by the Wheeling Sandy Loam. The soils sampled at SWMU 54 contained a relatively high percentage of sand, and are generally characterized as silty sand. The background samples from the Wheeling Sandy Loam appeared to correlate well with the soils from SWMU 54 and SWMU 31. Some SWMU 31 samples contained relatively more silt and clay in the upper 15 feet, and displayed a sand and gravel layer at about 15 feet below ground surface (bgs).

3.4.3 Soil Type 3: Cotaco Loam

3.4.3.1. The Cotaco Loam soil has a variable slope between 0 and 15 percent. The seasonal high water table is at a depth of about 2.5 feet; it is more than 60 inches deep to bedrock. The surface layer is typically a 9-inch-thick layer of brown loam. The subsoil, which extends to a depth of 60 inches or more, is yellowish-brown loam and clay loam and is mottled. This soil type is found in a small area near the eastern end of the Horseshoe Area at RAAP.

3.4.3.2. The permeability of the Cotaco soil is moderate, natural fertility is low, and organic matter content is moderately low, available water capacity is moderate. The less steeply sloped areas of this soil are prime farmland and are well suited to cultivate crops grown in the area. The permeability of this soil causes a hazard of seepage in landfills.

3.4.4 Soil Type 4: Braddock Loam

3.4.4.1. The Braddock Loam soil has a variable slope between 2 and 30 percent. This soil is more than 60 inches deep to bedrock and does not have a seasonal high water table within six feet of the surface. At RAAP, the Braddock Loam comprises about 70 percent of the up-land regions of the Horseshoe Area. Typically, the surface layer is a dark yellowish-brown loam, seven inches thick. The subsoil, which is a yellowish-red and red clay, extends to a depth of 60 inches or more.

3.4.4.2. The permeability of the Braddock Loam soil is moderate, natural fertility is low, and organic matter content is moderately low. The soil is acidic or very strongly acidic. The less steeply sloped areas of this soil are prime farmland and well suited to all locally grown cultivated crops.

3.4.4.3. During the soil background metals study, these soils were sampled throughout the Horseshoe Area. Although the lithology of the upper 60 inches of the background soil samples collected did not corresponded well with the description of the Braddock Loam as given above, the background samples collected did correlate well with the soils observed at SWMU 48. SWMU 48 is underlain by the Braddock Loam. Specifically, both areas are predominantly underlain by red-brown to orange-brown silt with some sand and clay. At depth, variable amounts of a red-brown to orange-brown clay-rich layer was observed.

3.4.5 Soil Type 5: Carbonate Rock Outcrop

3.4.5.1. This unit consists of steep and very steep soils and rock outcrop. The depth of bedrock is between 10 and 40 inches. At RAAP, this unit forms a narrow strip along the slopes of the southern boundary of the Horseshoe Area. The area of this unit is made up of about 50 percent rock outcrop and 50 percent soils. Typically the soils are a yellowish-brown silty clay loam about seven inches thick. The subsoil is strong brown clay, 26 inches thick. Limestone or dolomite bedrock is typically at a depth of 31 inches.

3.4.6 Soil Type 6: Unison-Urban Land Complex

3.4.6.1. This complex of soils varies in slope from 2 to 25 percent. The Unison-Urban Land Complex consists of about 50 percent deep and well drained Unison soils, 30 percent Urban land, and 20 percent other soils. This complex makes up about 70 percent of the surface area in the Main Manufacturing Area of RAAP. In an undisturbed area, the Unison soils have a surface layer of dark brown loam about 15 inches thick. The subsoil is a yellowish-red, sticky plastic clay about 43 inches thick, this layer is underlain by a red sandy clay loam to a depth of 58 inches. Urban land is land covered by pavement or structures; the original soil has been so altered or obscured that classification is not practical.

3.4.6.2. Permeability is moderate in Unison soils, natural fertility is low, and organic matter content is low to moderate. The soil is medium to strongly acidic. Cultivation of various vegetables is good in this soil; crop production is limited in disturbed areas.

3.4.6.3. During the soil background metals study, these soils were sampled throughout the Main Manufacturing Area. The lithology of the upper seven feet of the background soil samples collected consisted primarily of brown to red-brown clay with some silt and sand. This composition corresponds well with the above description of the Unison Soils. This clay-rich layer is typically underlain by a brown sand to about 10 feet bgs, which then grades into a brown clay. The Unison-Urban Land Complex soils observed at SWMU 17 consisted of a brown to yellow-brown clay-silt mixture which was often directly over the weathered bedrock. The SWMU 17 soils sampled generally correlated with the background soil samples collected from this soil type.

3.4.7 Soil Type 7: Udorthents and Urban Land

3.4.7.1. This soil class is about 45 percent Udorthents, 30 percent Urban Land, and 25 percent other soils. Udorthents are soils with variable characteristics. The surface layer is 5-15 inches thick and variable in color and texture. This soil type comprises less than 10 percent of the surface area in the Main Manufacturing Area of RAAP.

3.4.7.2. Permeability of Udorthents ranges from slow to moderately rapid. Other physical and chemical characteristics are also variable.

3.4.8 Soil Type 8: Ross Soils

3.4.8.1. Ross Soils are deep, nearly level and well drained. These soils are on levees and floodplains adjacent to streams and are commonly flooded for very brief periods. This soil makes up less than 5 percent of the area of the Main Manufacturing Area of RAAP, along the New River. Typically, the surface layer is a dark brown loam about 10 inches thick. This layer is underlain by brown loam to a depth of 35 inches.

3.4.8.2. Permeability is moderate in Ross Soils, natural fertility, and organic matter content is high. Depth to bedrock is more than 60 inches. The soil is slightly acidic to moderately alkaline. Cultivated crops are well suited to these soils.

3.4.9 Soil Type 9: Caneyville-Opequon-Rock Outcrop Complex

3.4.9.1. This complex consists of about 30 percent Caneyville soils, 25 percent Opequon soils, 20 percent rock outcrop, and 25 percent other soils. This complex comprises about 15 percent of the main manufacturing area at RAAP and is found in the undeveloped areas at the southern portion of this facility. The Caneyville soils have a brown silt loam surface layer about eight inches thick. The subsoil is a yellowish-red plastic clay about 24 inches thick. This is underlain by a limestone bedrock at a depth of about 32 inches. The surface layer of the Opequon soil is a brown plastic silty clay loam about 4 inches thick. The subsoil is a yellowish-red very plastic clay about 11 inches thick. Limestone bedrock is at a depth of about 15 inches. Rock outcrop consists of limestone and dolomite.

3.4.9.2. Permeability is moderately slow in both the Caneyville and Opequon soils. Natural fertility and organic matter content is moderate for both soils. Cultivated crops are poorly suited for these soils; they are used mainly for woodland.

3.4.10 Soil Type 10: Mixed Soil Types

3.4.10.1. This undeveloped region consists of a variety of soil types comprising about five percent of the Main Manufacturing Area at RAAP. These soils have variable profiles and variable physical and chemical characteristics.

3.5. REGIONAL GEOLOGY

3.5.0.1. In June 1995, Parsons ES performed a mapping project of the complex geological structural features at RAAP. This effort was done to supplement the existing geologic data for the area and to address site specific deficiencies in the geologic database. Although the area surrounding RAAP has been mapped geologically in detail (Schultz, VDMR open file in preparation), the facility itself had not previously undergone rigorous geologic mapping due to the inaccessibility associated with high security restrictions. The results of the research and mapping associated with this project are included in this section.

3.5.1 Regional Geology of the Southern Appalachian Valley and Ridge Province

3.5.1.1. RAAP is located in the Valley and Ridge Physiographic Province of southwestern Virginia. This province consists of closely spaced valleys and ridges that are directly related to folds in the underlying Paleozoic sequence of rocks. A nearly complete 4000 meter thick section of Cambrian through Pennsylvanian age sedimentary rocks is present in the Valley and Ridge province. Therefore, this area displays a reasonably complete history of the Paleozoic Era, from 550 to 300 million years ago. This history includes a series of sea level transgressions and regressions, as well as at least two major orogenic (mountain building) events. The transgressions are recorded by the deposition of marine sediments (carbonates/dolomite) and the regressions are evidenced by clastic deposition. The orogenic events are recorded by deformation (faulting, folding and cleavage) in the rocks.

3.5.1.2. From the Cambrian through Ordovician periods, primarily carbonates were deposited in the area that became the Valley and Ridge province. These rocks record the presence of a shallow warm sea, much like the present day Caribbean, extending from eastern Canada through Alabama. During this time, the east coast of North America was rotated parallel to, and within 15 degrees of the equator. A series of clastic (terrestrial) sedimentary rocks with minor amounts of carbonate were deposited from the Late Ordovician through Pennsylvanian periods. Most of RAAP is underlain by Cambrian-aged carbonates and clastic rocks of the Elbrook Formation and similar rocks of Ordovician age. Much younger Mississippian-aged shales and mudstones of the Mccrady/Price Formations are also present at RAAP.

3.5.1.3. All of the rocks of the Valley and Ridge display evidence of Paleozoic deformation. The first deformational episode began in the Mid-Cambrian and lasted through the Devonian period. This compressional event was responsible for the formation of the Blue Ridge Mountains, located immediately east of the Valley and Ridge province. However, little evidence of this Early Paleozoic deformational event is preserved in the rocks of the southern Valley and Ridge province. Therefore, the rocks at RAAP display little evidence of this deformational episode. Most of the extensive folding and faulting observed in the southern Valley and Ridge province is attributed to the Late Paleozoic Alleghanian orogenic event. This event was caused by the collision of North America with a another major land mass to the east in the Mid-Pennsylvanian period. The folds and faults in the southern Valley and Ridge were caused by an extended period of compression resulting in a series of deformational events.

3.5.1.4. During the Mesozoic Era, eastern North America experienced extension related to the opening of the proto-Atlantic Ocean. This extensional event produced the Mesozoic rift valleys to the east, such as the Culpeper Basin in Fairfax County. These basins filled with lacustrine and terrestrial sediments, leading to deposition of the characteristic red beds and black shale layers. Occasionally these beds contain abundant dinosaur footprints. From the Mesozoic Era to the present, the Valley and Ridge province has experienced gentle uplift and constant erosion.

3.5.2 Structural History of the Southern Appalachian Valley and Ridge Province

3.5.2.1. The structure of the Valley and Ridge province from southern Virginia to Tennessee is extremely complex due to the presence of extensive thrust faulting. The Valley and Ridge province north of this area is relatively unfaulted and consists of a series of northeast trending folds. Commonly these folds have overturned northwest limbs. In the south, faulting and folding occurred simultaneously, producing a series of northwest directed thrust faults. These thrust faults are often folded, and cut through preexisting folds. The large scale faults and folds in the study area were produced throughout the Late Paleozoic orogenic event.

3.5.2.2. In the Blacksburg area, east of RAAP, Early Paleozoic folds (categorized as F1 folds) have been described (Bartholomew and Lowry, 1979). These F1 structures include isoclinal folds with axial planar foliation apparent in the Rome Formation. These folds are typically stretched out and sheared so that the axial-plane foliation approximately parallels bedding in most exposures.

3.5.2.3. Middle- to Late Paleozoic deformation is apparent in the rocks exposed at RAAP. At the outcrop scale, this deformation takes the form of tight folds (F2) which have refolded the F1 folds. F2 folds are commonly associated with well developed slip cleavage in the Rome Formation (Bartholomew and Lowry, 1979). The F2 structures include several generations of isoclinal, asymmetric, sometimes overturned folds (Bartholomew and Lowry, 1979).

3.5.2.4. The Late Paleozoic deformational event produced the Pulaski thrust fault in post-Early Mississippian time as a result of northwest-directed shortening. The Pulaski thrust is the largest of several major southeast-dipping Alleghanian thrusts of the southern and central Appalachians (Schultz, 1988). It has been traced along strike approximately 310 miles (500 km) from near Staunton, Virginia, southward into Tennessee where it is overridden by rocks of the Blue Ridge thrust sheet. Based on seismic data, the Pulaski thrust originated well below the Blue Ridge thrust and extends into the Precambrian basement. Estimated displacement of the thrust near Radford ranges from 15 km to 50 km (Bartholomew and Lowry, 1979). At RAAP, Cambrian rocks are thrust over rocks of Mississippian age. Thus, the maximum age of thrust emplacement is Mississippian. The maximum thickness of the Pulaski thrust sheet ranges from 1500 m to 4000 m. The

decollement (detachment) of this thrust sheet is within shales and dolomites of the Lower Cambrian Rome formation. The Pulaski thrust sheet includes a series of imbricated (shingle-like) thrusts that record several periods of movement during the Late Paleozoic. Rocks of the Pulaski thrust sheet have typically undergone two-stages of Alleghanian deformation. The first stage involved decollement and ramp thrusting on Mississippian strata. The second stage involved folding and faulting of the thrust sheet. The second stage of deformation involved large-scale (several mile-long) folding resulting in broad east-west trending antiforms and synforms that warped the Pulaski thrust sheet. Most of RAAP lies above the Pulaski thrust fault. At several locations, including at RAAP, the Cambrian rocks in the Pulaski thrust sheet have been eroded away to display the younger Mississippian aged rocks below (windows). The older deformed rocks represent rootless tectonic slices of basement material (horses) that lie above relatively less deformed younger rocks.

3.5.2.5. Rocks of the Pulaski thrust sheet display low grade (lower greenschist facies) regional metamorphism as evidenced by conodont color alteration indicating a maximum temperature range of 300-400° C. Chlorite and muscovite occur in carbonates near the base of the Pulaski thrust sheet and were probably derived from clay minerals during regional metamorphism. The fault surface is rarely exposed. In the vicinity of RAAP, evidence of the close proximity to the thrust fault takes the form of tectonic breccia.

3.5.3 Geology of RAAP

3.5.3.1. RAAP is located in the New River Valley, at the northwest terminus of the southern Valley and Ridge province. The New River crosses the Valley and Ridge province approximately perpendicular to the regional strike of bedrock and it chiefly cuts Cambrian and Ordovician limestone and dolomite. The valley is covered by river flood plain and terrace deposits; karst topography is dominant. Deep clay-rich residuum is prevalent in areas underlain by carbonate rocks. Karst features include sinkholes, caverns and springs caused by the dissolution of calcium carbonate by naturally occurring carbonic acid in rainwater. The greatest areas of karst features are controlled by bedrock stratigraphy and structure, and by the presence of major drainages. Late Cambrian and Mid-Ordovician limestones are more soluble than Cambrian and Lower Ordovician dolomite and shaley dolomite; therefore, they have the greatest number of sinkholes and caverns. However, both rock types show increased karst development in areas of; low bedrock dip, where bedding is intensely folded, cleaved or jointed, and near major drainages.

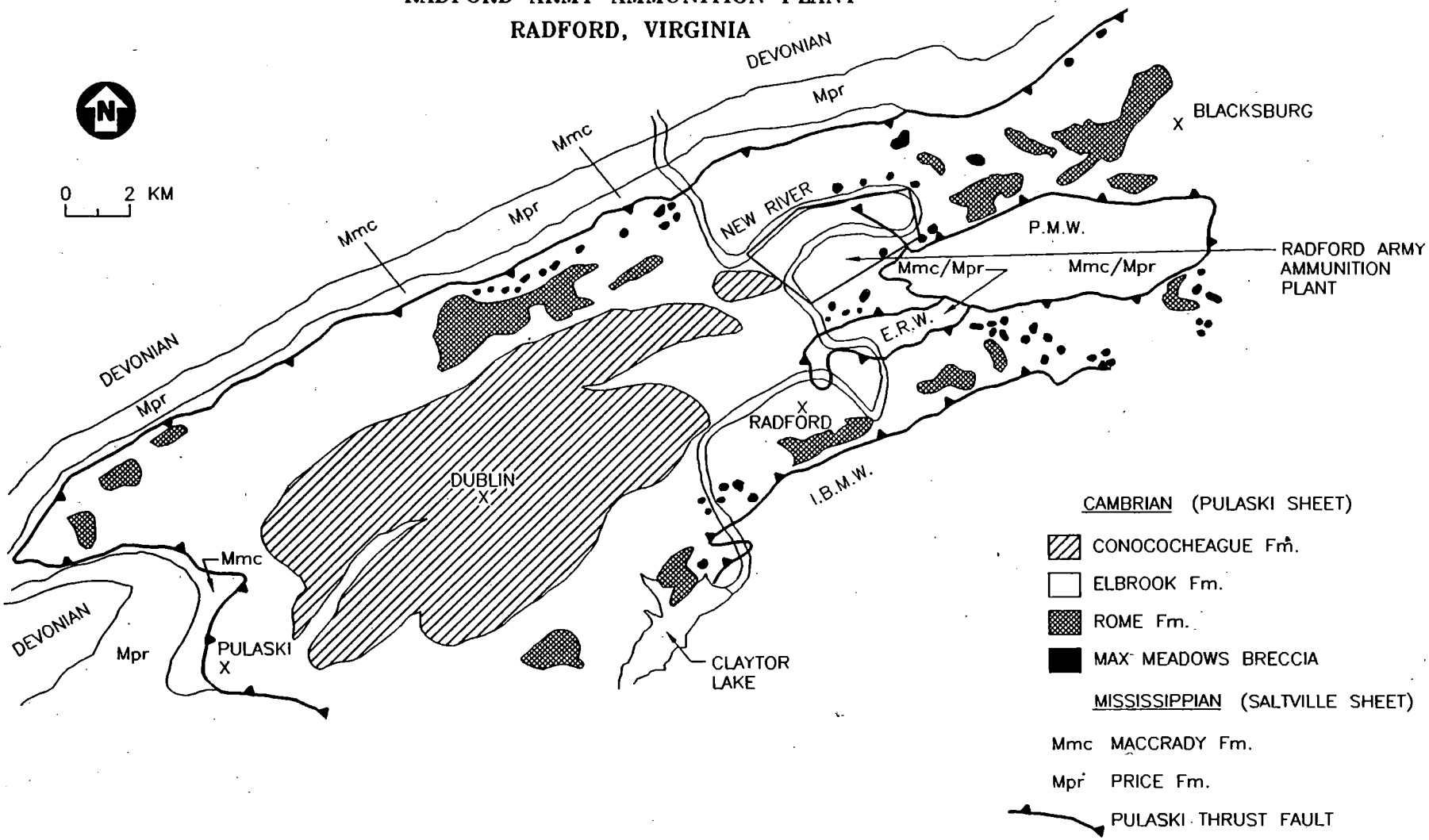
3.5.3.2. As shown in Figure 3.2, RAAP occupies the central portion of the Pulaski fault thrust sheet (Schultz, 1988). RAAP is underlain by four major rock units and one unconsolidated sedimentary unit that range in age from Cambrian to Quaternary. The rock units are: Cambrian Formations (Elbrook, Rome, and Conococheague) and Mississippi Formations (Mccrady/Price). Only the Elbrook and Mccrady/Price Formations outcrop at RAAP. Dip of the rock units varies over RAAP from nearly horizontal to nearly vertical. However, typical dips are in the range of 20 to 30 degrees. The unconsolidated sediments are of Quaternary age and include alluvial, residual, and colluvial deposits. Table 3.4 is the legend to Figure 3.3, a geologic map of the major consolidated rock formations at RAAP. The consolidated and unconsolidated formations at RAAP are described below (USAEHA, 1980).

3.5.3.3. The *Elbrook Formation* is a major rock unit cropping out at RAAP. This Formation is composed of thickly bedded, blue-gray dolomite interspersed with blue-gray to white limestone; brown, green, and red shale; argillaceous limestone; and brecciated limestone (colors range from mottled light- to dark-gray and yellow-brown). Sinkholes, solution channels, pinnacled surfaces, and springs are common to the Elbrook. This Formation ranges from 1,400 to 2,000 feet thick. The strike of bedding in the Elbrook Formation is variable throughout the region. The general orientation of bedding is seen in the nearly east-west alignment of sinkholes at RAAP and the surrounding area. Most sinkholes in the area are oval shaped and elongated with respect to the strike of the bedding; they most likely represent fractured or faulted zones within the underlying Elbrook Formation.

3.5.3.4. The *Rome Formation* underlies the Elbrook Formation; however, the Rome does not crop out at RAAP. This Formation is composed of red and green shales, sandstone, dolomite, and limestone. The red shales commonly mark the basal unit. Thickness ranges from 1,000 to 2,000 feet.

3.5.3.5. The *Conococheague Formation* overlies the Elbrook Formation and is composed of limestone, dolomite, and sandstone. It ranges in thickness from about 2,200 feet to 1,700 feet. This unit does not crop out within RAAP.

FIGURE 3.2
GEOLOGIC MAP OF THE PULASKI THRUST SHEET IN THE VICINITY OF RAAP
RADFORD ARMY AMMUNITION PLANT
RADFORD, VIRGINIA



NOTE:
P.M.W., PRICE MOUNTAIN WINDOW; E.R.W., EAST RADFORD WINDOW, I.B.M.W., INGLES–BARRINGER MOUNTIAN WINDOW. FIGURE MODIFIED AFTER A. SCHULTZ (1983).

TABLE 3.4

LEGEND TO THE BEDROCK GEOLOGIC MAP of the RADFORD ARMY AMMUNITION PLANT

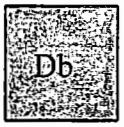
Rock Characteristics[1]

Paleozoic

Mississippian

Lower Mccrady Fm., sandstones overlain by mottled maroon and green mudstones. Upper Price Fm., mottled maroon and green mudstones underlain by dark gray to black mudstone and coal.

Devonian



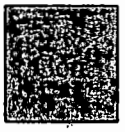
Brailler Fm., interbedded sequence of dark-gray to black mudstone, medium-gray siltstone and fine-grained commonly crossbedded sandstone.

Ordovician

Undivided Knox Group, light- to medium-gray, massive, thick-bedded, fine- to medium-grained dolomite interbedded with massive to layered gray chert.

Cambrian

Max Meadows tectonic breccia, poorly sorted angular to subrounded clasts of dolomite and calcareous mudstones in a fine- to very fine-grained matrix of crushed dolomite.

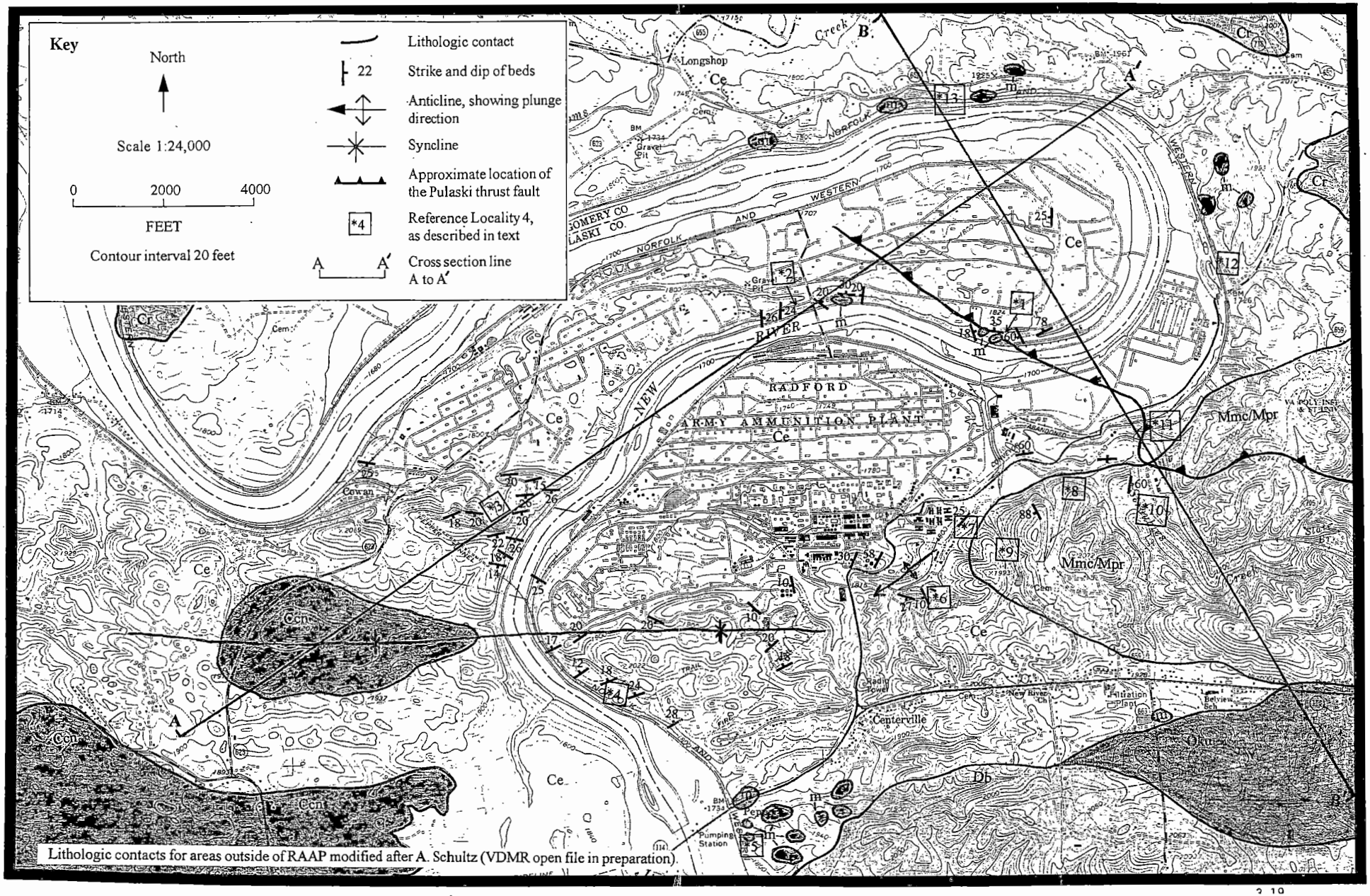


Conococheague Fm., limestones, dolomite, and sandstone. The Formation is approximately 2000 feet thick.

Elbrook Fm., cyclic sequences of medium-gray, finely laminated, fine-grained dolomite. Limestone units range up to 50 feet in thickness. The percentage of limestone diminishes downward.

Rome Fm., interbedded mottled maroon and green phyllitic mudstone, fine-grained sandstone and siltstone, and dark-gray, fine-grained dolomite.

[1] Lithologic contacts for areas outside of RAAP modified after A. Schultz (VDMR open file in preparation). Lithologic descriptions modified after Bartholomew and Lowry (1979).



Lithologic contacts for areas outside of RAAP modified after A. Schultz (VDMR open file in preparation).

3.5.3.6. Mississippian rocks of the *Mccrady/Price Formations* outcrop in a fenster (window) east of the main plant area along Stroubles Creek. This Formation consists of mottled red and green shale and mudstone interspersed with brownish-green siltstone and sandstone. The Formation may be up to 1,500 feet thick.

3.5.3.7. The *Max Meadows tectonic breccia*, which is evidence of the close proximity of the Pulaski fault surface, was observed within and in the vicinity of RAAP. This tectonic breccia consists of poorly sorted, angular to subrounded clasts of massive dolomite, laminated dolomites, and finely-laminated greenish gray calcareous mudstones in a fine- to very fine-grained matrix of crushed dolomite. Clasts range from less than 1 inch to more than 3 feet in length. The breccias are massive to crudely layered and are well to poorly indurated. The breccia, which is most fine-grained along the fault contact (Schultz, 1986a), is an integral part of the highly deformed rocks along the base of the Pulaski thrust sheet. Tectonic breccia has been described along the entire strike (310 miles) of the Pulaski thrust sheet. The tectonic breccia which occurs well above the basal Pulaski fault surface (up to 900 feet above), decreases in abundance away from this contact. The breccia probably formed by cataclastic (brittle) deformation associated with the emplacement of the Pulaski Fault. The clasts have undergone rigid-body rotation and size reduction within a fine-grained deformed dolomite matrix. The breccia typically exists as either sill-like bodies parallel to bedding that may be folded, or as dike-like bodies that truncate bedding. These bodies display irregular map patterns and may range in scale from less than 1 inch to several hundred feet in width. Schultz (1986a) describes specific outcrops of the Max Meadows tectonic breccia in the vicinity of RAAP.

3.5.3.8. Figure 3.3 summarizes the geologic mapping conducted at RAAP by Parsons ES. The majority of this facility is underlain by the Elbrook Formation. Small-scale folds and faults are apparent on virtually all rock exposures within the facility. Bedding strike and dip measurements are displayed on Figure 3.3. A large-scale syncline is present trending east-west in the western region of RAAP. A large-scale anticline is apparent plunging to the southwest in the southeastern region of the plant. The Max Meadows breccia, which was observed in abundance in the southeastern region of the horseshoe area, is interpreted as evidence of the close proximity of the Pulaski thrust fault surface. Therefore, this significant subsurface feature controlling structural and hydrogeological activity, is present on site. Previous work did not extend the fault through the site (Schultz, VDMR open file in preparation). Thirteen Reference Localities are

identified on Figure 3.3. Table 3.5 summarizes field data and observations for each of these Reference Localities. Geologic cross-sections A-A' and B-B' are presented in Figures 3.4 and 3.5, respectively. These cross-sections demonstrate the structural complexity of this region. Note in these figures that the Elbrook Formation within RAAP has been thrust upon younger Mississippian-aged rocks. All of these rocks were then folded into broad anticlines and synclines, which have wavelengths on the order of 10,000 to 12,000 feet. The folds were then eroded. The thrust sheet has been breached by erosion, exposing Mississippian sandstones and shales of the McCrady/Price Formation in a fenster east of the main plant area, along Stroubles Creek (Figures 3.3 and 3.5). Figures 3.6 and 3.7 are photographs that correspond with Reference Localities described in Table 3.5. The outcrop cross-sections in Figure 3.8 also correspond with Reference Localities described in Table 3.5.

3.5.3.9. Unconsolidated sediments (overburden) mantle the major portion of RAAP. These include alluvial plain sediments deposited by the New River prior to entrenchment, residual deposits from in-place weathering of parent bedrock, and colluvial deposits developed by residual slope wash. Alluvial plain deposits commonly line the New River and Stroubles Creek; some as recent floodplain material and some as geologically older terraces. Table 3.6 is the legend to Figure 3.9 which displays the location of river terrace deposits in the vicinity of RAAP. This figure also summarizes structural data outside of RAAP as presented by Schultz (VDMR open file in preparation). On the horseshoe loop, three terraces are evident. In general, there is a textural fining upwards in these terrace deposits. Gravels and silty, clayey sands form the basal unit. These are overlain by finer micaceous silts and clays. Sporadic cobbles and boulders (known as river jack) occur as lenses throughout the alluvial strata. Thickness of the alluvial deposits varies from a few feet to 50 feet, with an average of 20 feet. Residual deposits (clays and silts) are a result of chemical and physical weathering of the parent bedrock (primarily Elbrook dolomite at RAAP). Most of RAAP is covered by residual deposits. In most cases along the New River and in the Horseshoe Area, these residual deposits underlie the alluvium, except where the residuum has been eroded to bedrock and replaced by alluvium. The depth of the overburden varies from a few feet to 70 feet.

3.5.3.10. Colluvial deposits are generally formed from mass-wasting of slopes and escarpments. In general, these deposits are a heterogeneous mixture of alluvium, residuum, and rock debris that has moved from its original position. These deposits are generally interbedded between the strata of alluvium and residuum; thickness is variable.

TABLE 3.5

REFERENCE LOCALITY DESCRIPTION

Reference Locality 1	Several isolated outcrops of the Elbrook Formation and Max Meadows Breccia along hillside between SWMU 48 and SWMU 13. Orientation of bedding in the Elbrook varies due to small scale folding; however, bedding is generally oriented N40°W, 30 NE. Joints are apparent in some outcrops. The Max Meadows Breccia displays a distinctive brown-red weathering pattern with many voids (solution channels). This unit consists of angular and subrounded dolomite clasts in a well indurated fine-grained dolomite matrix. 8 to 12 foot tall pinnacles of the breccia with extensive solution channels are present approximately 400 feet west of Reference Locality 1. The breccia in this region was not observed in direct contact with the Elbrook.
Reference Locality 2	Series of hillside outcrops of the Elbrook Fm. west of the New River bridge in the horseshoe area. Thick to thinly bedded, gray to brown limestone with bedding generally oriented N10°E, 24SE. Deformation in the limestone is less intense than in the vicinity of Reference Locality 1. Localized areas of breccia are present which grade to relatively undeformed limestone. East of Reference Locality 2, about 800 feet east of the New River bridge, an antiform trending N10°E is apparent. Relatively undeformed dolomite is present in the upper beds near the crest off the antiform, while breccia is observed in the underlying beds near the core of the antiform.
Reference Locality 3	Numerous exposures of the Elbrook are displayed in the vicinity of Reference Locality 3, within the ballistics test area. These exposures are found along the roadsides and at the tops of the limestone cliffs overlooking the New River in this region. Thinly bedded to laminated fissile, tan to light-gray, limestone with bedding generally oriented N80°W, 26SW is present along the roadsides in the ballistics test area, east of Reference Locality 3. Outcrops at the cliff tops south of Reference Locality 3 consist primarily of gray thin to medium bedded micritic limestone, with bedding generally oriented N60°W, 30SW. Minor amounts of deformation is apparent in the Elbrook in this vicinity. Rocks in this area represent the northern limb of a large scale syncline that bisects the western region of RAAP.

TABLE 3.5

REFERENCE LOCALITY DESCRIPTION (CONTINUED)

Reference Locality 4	Numerous cliff side outcrops of the Elbrook in the southern limb of the syncline referred to in Reference Locality 3. The beds are typically oriented N70°E, 15NW. The Elbrook in this region is generally dark-gray, fine-grained limestone with minor deformation. Some laminated to thinly bedded light-gray, fine-grained dolomite is interbedded with the more abundant limestone.
Reference Locality 5	Outcrops of the Max Meadows breccia and Elbrook Fm as described by Schultz (1986a). The Pulaski thrust fault is exposed at this locality. The breccia consists of poorly sorted, angular to subrounded clasts of massive dolomites, laminated dolomites, and finely laminated greenish-gray calcareous mudstones in a fine- to very fine-grained matrix of crushed dolomite (Figure 3.6). Clasts range from less than 1 inch to more than 3 feet long. The breccias are massive to crudely layered and are well to poorly indurated. Breccia is finest grained along the fault contact. Dolomite is present between the tectonic breccias of the hanging wall of the Pulaski thrust and the Devonian Millboro Shale in the footwall (Schultz, 1986a).
Reference Locality 6	A large roadcut in the TNT area exposing approximately a 150 foot section of the Elbrook Fm. Distinct units are apparent within the outcrop including; a medium-to thickly-bedded, tan and gray limestone; a thickly bedded, light-gray limestone that weathers dark-gray; a thinly bedded, to shaley, light-tan dolomite; and a dark-gray thin to medium bedded limestone (Figure 3.7). The orientation of bedding varies somewhat throughout the roadcut, but is generally N60°W, 20SW. Three distinct sets of joints are apparent. These joint sets are oriented; N30°W, 70NE; N50°W, vertical; and N70°E, 88NW. Vertical faults (tensional?) with minor offsets are apparent, the fault surfaces are oriented N60°E. Calcite filled fractures are locally abundant in the thickly bedded units, many of which are oriented N70°W, 25SW.

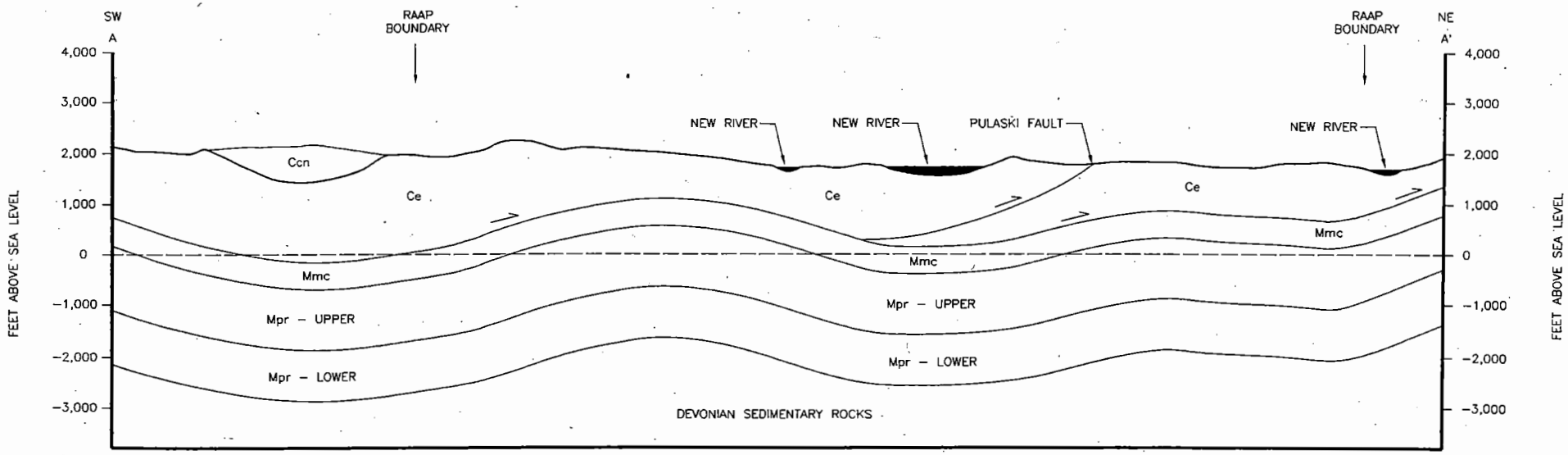
TABLE 3.5

REFERENCE LOCALITY DESCRIPTION (CONTINUED)

Reference Locality 7	A 12 foot high by 60 foot long roadside outcrop in the vicinity of the TNT area of thinly bedded light-gray to shaley dolomite unit of the Elbrook Fm. This unit weathers tan. Numerous small scale folds are apparent in this outcrop, bedding is generally oriented N47°E, 25NW. Localized areas of the Max Meadows breccia are present.
Reference Locality 8 and Reference Locality 9	Isolated outcrops of fine- to medium-grained red brown sandstone. These rocks are interpreted as being part of the undifferentiated Mccrady and Price Formations.
Reference Locality 10	Large roadcut along Virginia State Road 659 outside and adjacent to RAAP property. Interbedded fissile shales and siltstones of the undifferentiated Mccrady and Price Formations. Bedding is generally oriented N5°W, 50NE. The rocks weather red-brown, but are greenish gray on fresh surfaces.
Reference Locality 11, Reference Locality 12 and Reference Locality 13	Approximate locations of cross-sections described by Schultz (1986b) and presented in Figure 3.8. Note in Figure 3.8 that the breccia occurs as both sill-like bodies (bedding-parallel) or as dike-like bodies which truncate bedding.

FIGURE 3.4
GEOLOGIC CROSS SECTION A–A' OF RAAP AND ADJACENT AREAS

RADFORD ARMY AMMUNITION PLANT
RADFORD, VIRGINIA



VERTICAL AND HORIZONTAL SCALE = 1:24,000

0 1,000 2,000
FEET

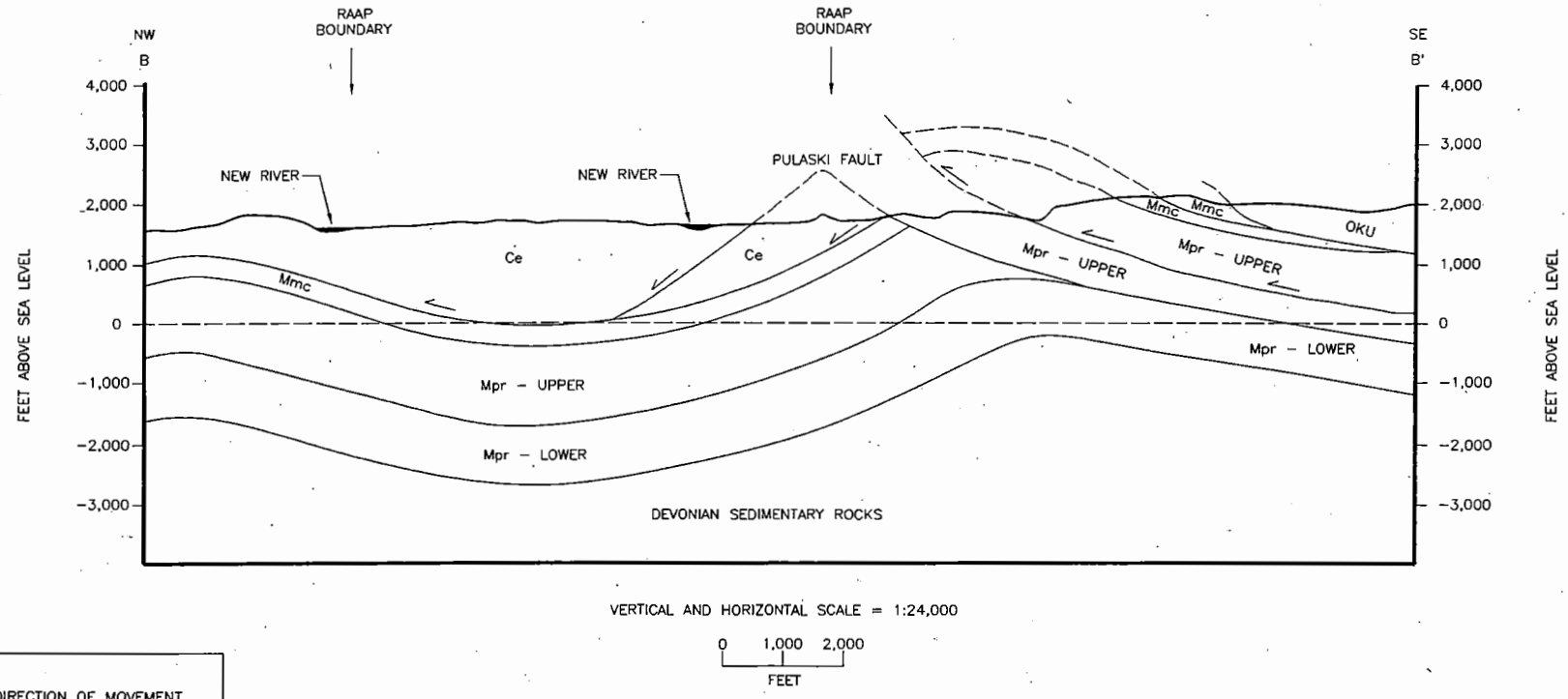
KEY

→ DIRECTION OF MOVEMENT ALONG THE PULASKI THRUST FAULT

NOTE: Ccn CONOCOCHEAGUE Fm.; Ce, ELBROOK Fm.; Mmc, MCCRADY Fm.; Mpr, PRICE Fm.

FIGURE 3.5
GEOLOGIC CROSS SECTION B–B' OF RAAP AND ADJACENT AREAS

RADFORD ARMY AMMUNITION PLANT
RADFORD VIRGINIA



VERTICAL AND HORIZONTAL SCALE = 1:24,000

0 1,000 2,000
FEET

KEY

← DIRECTION OF MOVEMENT ALONG THE PULASKI THRUST FAULT

– – – POSITION OF GEOLOGIC FEATURES PRIOR TO EROSION.

NOTE: Mmc, MACCRADY Fm; Mpr, PRICE Fm; OKU, UNDIVIDED KNOX GROUP; Ce, ELBROOK Fm. FIGURE MODIFIED AFTER A. SCHULTZ (VDMR OPEN FILE IN PREPARATION.)

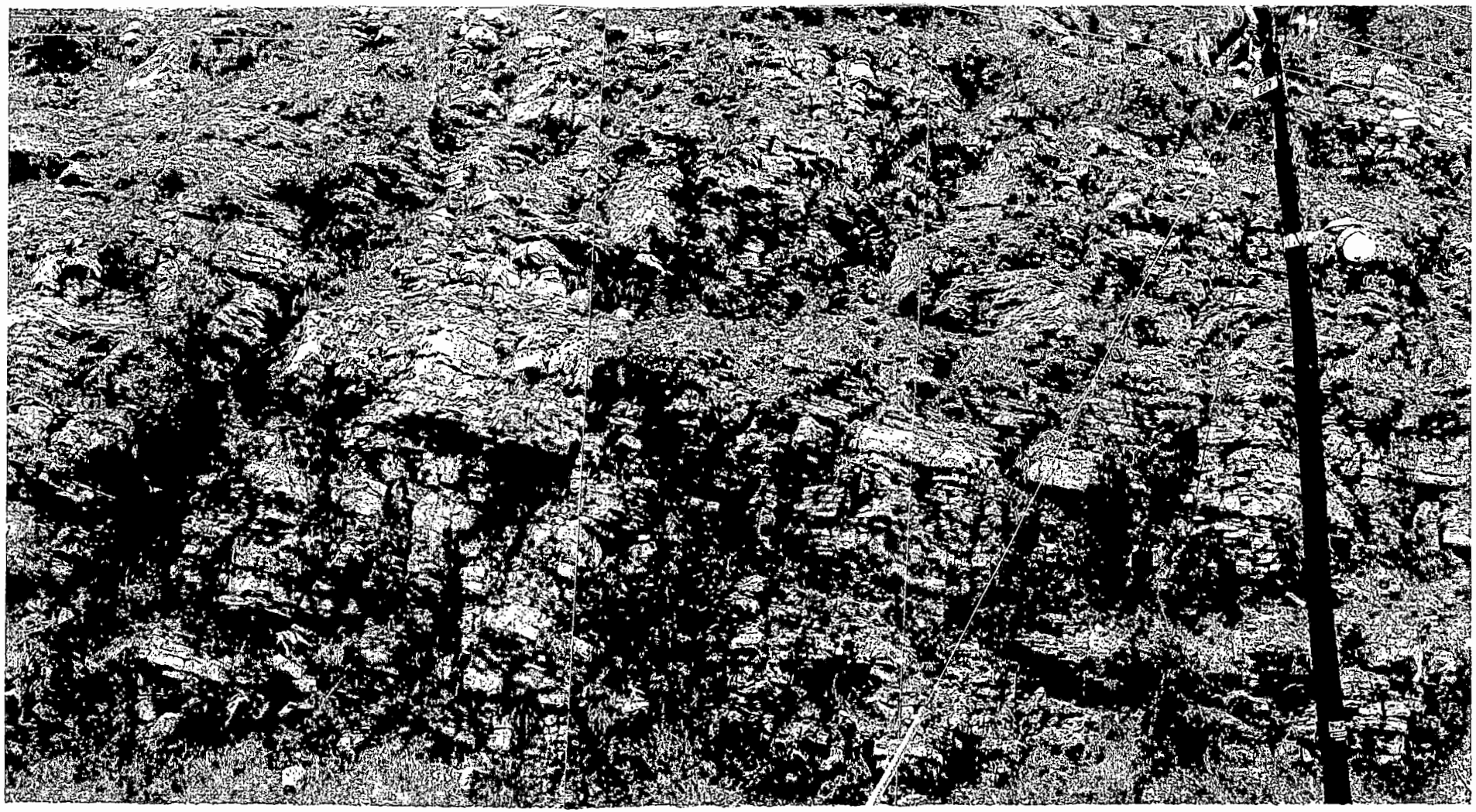
FIGURE 3.6
PHOTOGRAPH OF AN OUTCROP OF THE MAX MEADOWS BRECCIA

RADFORD ARMY AMMUNITION PLANT
RADFORD, VIRGINIA

Note: Photograph of a railroad cut exposing a weathered surface of the Max Meadows tectonic breccia in the vicinity of Reference Locality 5. See Table 3.5 for description.

FIGURE 3.7
PHOTOGRAPH OF AN OUTCROP OF THE ELBROOK FORMATION

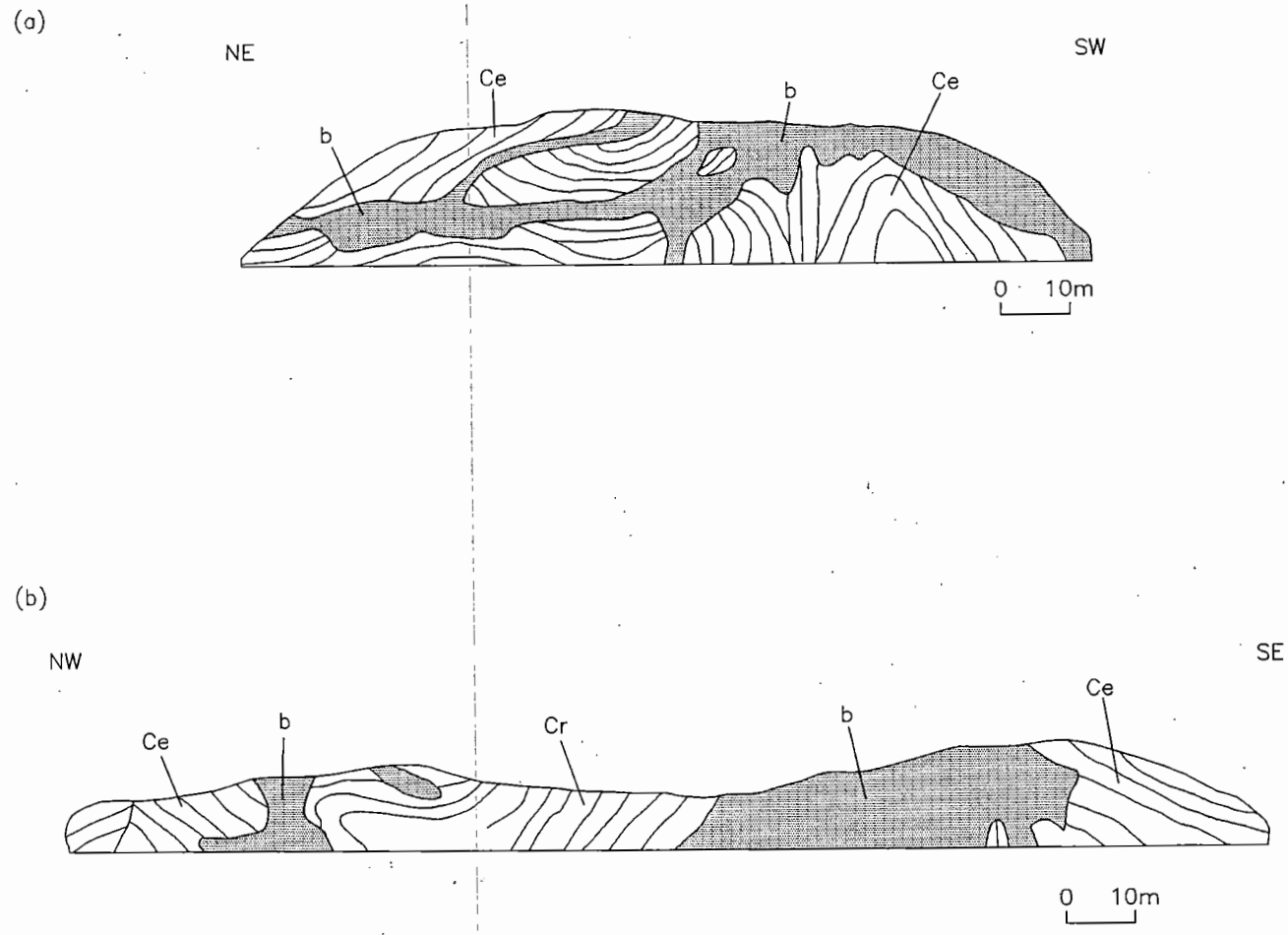
RADFORD ARMY AMMUNITION PLANT
RADFORD, VIRGINIA



Note: Photograph of a road cut exposing a large section of the Elbrook Formation at Reference Locality 6. See Table 3.5 for

FIGURE 3.8
OUTCROP SECTIONS IN THE VICINITY OF RAAP

RADFORD ARMY AMMUNITION PLANT
RADFORD, VIRGINIA



(a) SKETCH OF OUTCROP EXPOSURE AT REFERENCE LOCALITY 11. FOLDED, FAULTED AND BRECCIATED ELBROOK DOLOMITE.

(b) SKETCH OF OUTCROP EXPOSURE AT REFERENCE LOCALITY 12. FOLDED AND FAULTED ROCKS OF THE ROME AND ELBROOK FORMATIONS AND MAX MEADOWS.

Ce: ELBROOK Fm. Cr: ROME Fm. b: MAX MEADOWS BRECCIA

FIGURE MODIFIED AFTER A. SCHULTZ (1983).

J:\CADD\722843\72284304

TABLE 3.6

LEGEND TO THE GEOLOGIC MAP of RAAP SHOWING RIVER TERRACE DEPOSITS

Rock Characteristics[1]

Quaternary

Terrace deposits, unconsolidated, poorly stratified deposits of dark-brown to dark-reddish-brown, 2-8 inch thick well rounded cobbles in an extensively weathered soil matrix.

Paleozoic

Mississippian

Mmc/ Mpr

Lower Mccrady Fm., sandstones overlain by mottled maroon and green mudstones. Upper Price Fm., mottled maroon and green mudstones underlain by dark gray to black mudstone and coal.

Devonian

Db

Brailler Fm., interbedded sequence of dark-gray to black mudstone, medium-gray siltstone and fine-grained commonly crossbedded sandstone.

Ordovician

Oku

Undivided Knox Group, light- to medium-gray, massive, thick-bedded, fine- to medium-grained dolomite interbedded with massive to layered gray chert.

Cambrian

m

Max Meadows tectonic breccia, poorly sorted angular to subrounded clasts of dolomite and calcareous mudstones in a fine- to very fine-grained matrix of crushed dolomite.

Ccn

Conococheague Fm., limestones, dolomite, and sandstone. The Formation is approximately 2000 feet thick.

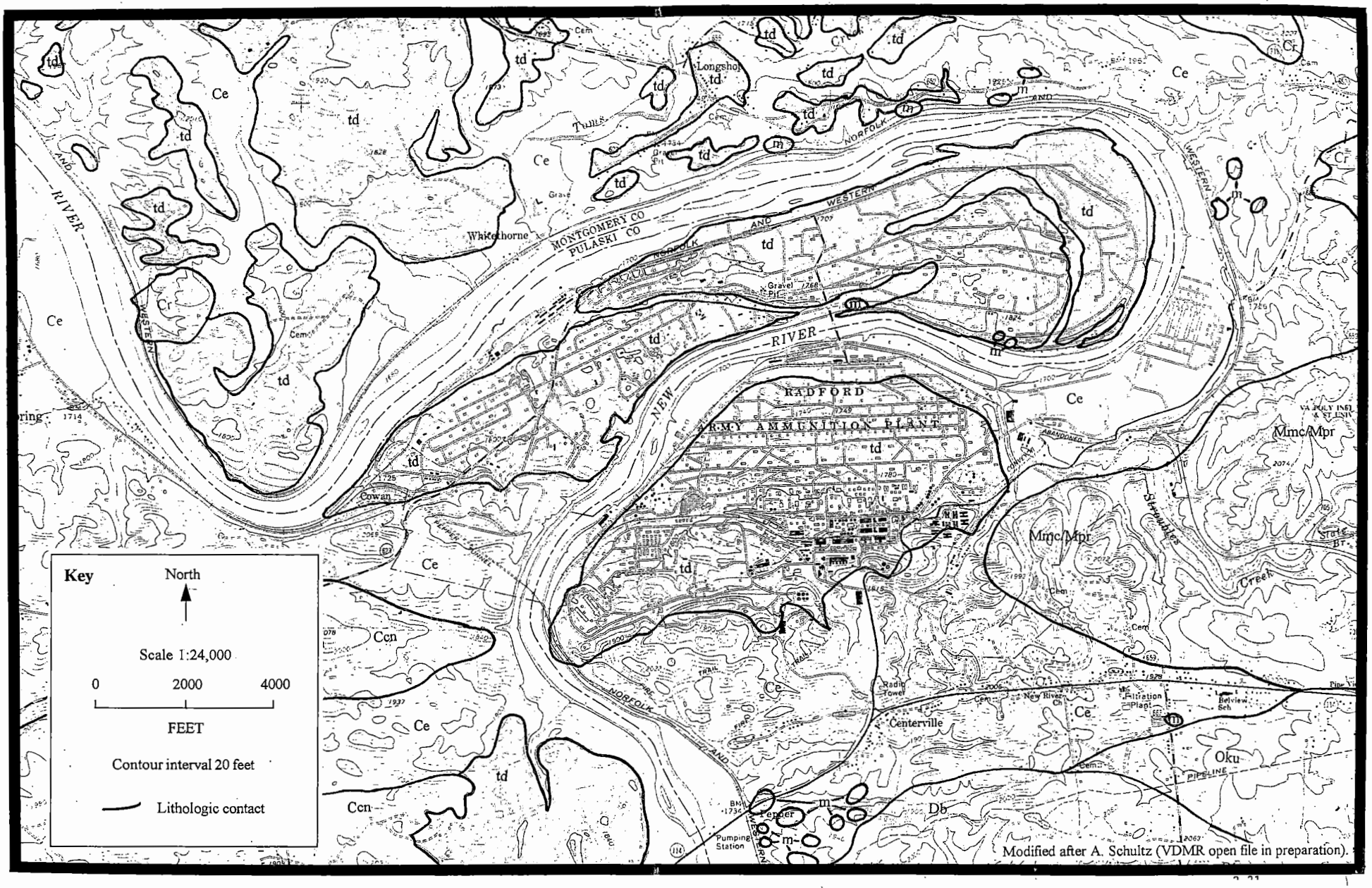
Ce

Elbrook Fm., cyclic sequences of medium-gray, finely laminated, fine-grained dolomite. Limestone units range up to 50 feet in thickness. The percentage of limestone diminishes downward.

Cr

Rome Fm., interbedded mottled maroon and green phyllitic mudstone, fine-grained sandstone and siltstone, and dark-gray, fine-grained dolomite.

[1] Geologic map modified after A. Schultz (VDMR open file in preparation). Lithologic descriptions modified after Bartholomew and Lowry (1979).


Key
North
Scale 1:24,000
0
2000
4000
FEET
Contour interval 20 feet
Lithologic contact
RADFORD
ARMY AMMUNITION PLANT
NEW RIVER
MONTGOMERY CO
PULASKI CO
NORFOLK AND WESTERN
Whitethorne
Cowan
Centerville
Ce
td
Ccn
Db
Mmc/Mpr
Oku
Modified after A. Schultz (VDMR open file in preparation).

3.5.3.11. No evidence of recent faulting exists in the vicinity of RAAP. However, the Radford area has experienced seven earth tremors in the last 200 years with a recorded intensity of VI or higher on the Modified Mercalli Scale (USAEHA, 1980a). Several recent studies (Bollinger and Wheeler, 1983, 1988) have delineated a low level seismic zone in the central and northwestern part of the Valley and Ridge province in Giles County, VA. The largest recorded quake occurred in 1897, had a modified Mercalli Intensity of VIII, and was centered in Pearsburg, VA. Schultz and Southworth (1989) have shown that the largest slope failures in the folded Appalachians occur in the Giles County Seismic Zone, immediately northwest of RAAP.

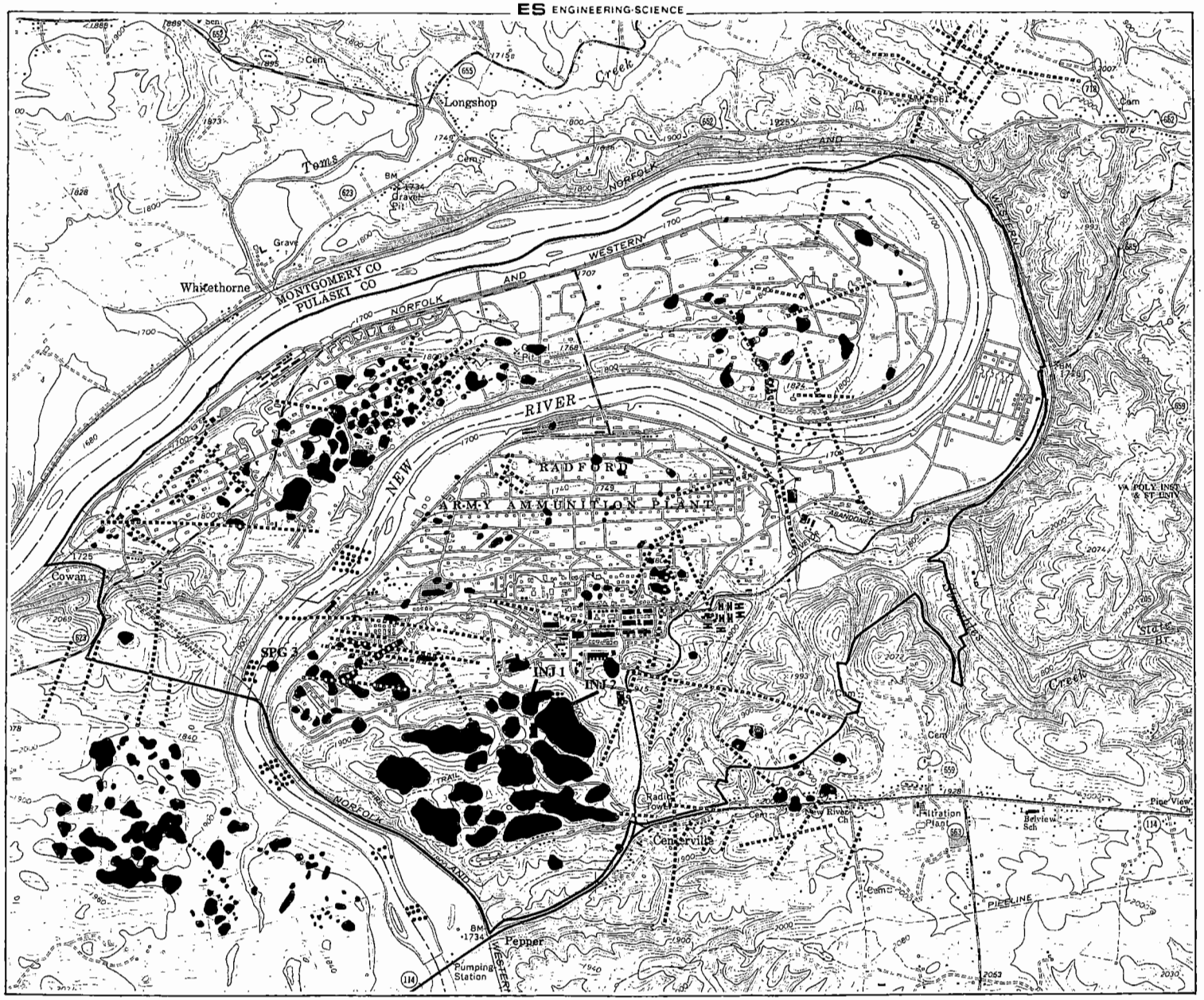
3.5.3.12. A total of 66 fracture traces were identified within and around RAAP in a photo geologic study conducted by the USEPA's Environmental Photographic Interpretation Center (EPIC) in 1992 (Figure 3.10). Fracture traces are linear features identified in aerial photographs that represent the surface expression of major fractures and/or zones of fracturing. These features may be expressed as soil-tonal variations and vegetational and topographic alignments and are significant factors controlling groundwater flow at RAAP. The fractures or fracture zones can act as conduits for groundwater, thereby increasing flow rates and, in some cases, redirecting flow away from the "expected" flow direction. In karst terrain, such features are environmentally significant because carbonate dissolution and resulting conduits develop along bedding planes as well as fractures (USEPA, 1992a).

3.6 REGIONAL HYDROGEOLOGY

3.6.0.1. The hydrogeologic conditions at RAAP are complex due to the karstic nature of the aquifer underlying this facility. The karst aquifier at RAAP is contained within limestone and dolomite. The most characteristic feature of a karst aquifier is the flow of groundwater through conduits (caves/caverns) and along bedding planes and fractures enlarged by solution. Commonly, karst aquifiers discharge to springs. Dissolution of carbonates only occurs in acidic waters. The most common cause of groundwater acidity is by the formation of carbonic acid from reaction of water with carbon dioxide in the atmosphere and soils. Several other sources of acidity that can be locally significant, such as aqueous hydrogen sulfide in reducing environments, have not been a factor at RAAP. Solution rates of limestone by waters undersaturated with respect to calcium carbonate have been shown to be rapid. Direct measurements of limestone dissolution have shown rates as high as 0.4 to 0.8 mm/year in perennially active passages. Compatible rates have been

FIGURE 3.10 FRACTURE TRACE/SINKHOLE LOCATION MAP OF RAAP

ES ENGINEERING-SCIENCE



LEGEND

- PROPERTY LINE
- FRACTURE TRACE
- BEDDING PLANE EDGE
- SINKHOLE
- SPRING LOCATION

NOTE: **INJ** DYE INJECTION LOCA
SPG SPRING LOCATION

N

SOURCE: USEPA, 1992
USGS, RADFORD (NORTH) VIRGINIA QUADRANGLE

0 2,000 4,000
FEET

SCALE 1: 24,000

produced by laboratory experiments (Howard and Howard, 1967). However, the rapid solution rate can hinder the formation of solution conduits. Measured rates are so high that water approaches saturation after only a short distance of travel. However, more recent work has shown that solution rates drop sharply as the water approaches chemical equilibrium with the rock. As a result, this water can penetrate a large distance into limestone while retaining its ability to dissolve the rock (Palmer, 1990). In most karst aquifers, dissolution by groundwater is highly selective. Although there may exist an abundance of presolution openings, very few are enlarged significantly during solutionization. The result is a sharp discontinuity in the scale of underground voids, with large caves surrounded by a network of tiny openings that have been enlarged very little, if at all. The larger conduits will develop along bedding plane partings or fractures that are most open initially or are favorably oriented along the prevailing hydraulic gradient. Sinkholes and conduits evolve interdependently. Sinkholes develop in the land surface at the groundwater input locations to the larger conduits as a result of concentrated dissolution, collapse and transport of overburden through the conduit by groundwater.

3.6.0.2. The initial development of solution conduits requires the through flow of water to carry away the dissolved material. Therefore, to develop a karst aquifer, a preexisting interconnected network of openings must be present between the recharge and discharge points. These openings include intergranular pores, fractures and bedding-plane partings. Fractures and bedding-plane partings are of nearly equal importance. Most karst aquifers show a combination of fracture and bedding plane control. Fault surfaces tend to have less of an affect on solutionization. Solutionization in intergranular pores is typically significant only in young poorly-indurated carbonates, where this process forms irregular voids like the pores in a sponge. Specific groundwater flow paths within a karst aquifer rarely follow the steepest component of the hydraulic gradient. Stratigraphic and structural data are necessary to explain local patterns of subsurface flow (Palmer, 1990). In massive rock with fractures, groundwater flow is typically discordant with bedding. In rocks with prominent bedding planes, such as at RAAP, the groundwater flow patterns are responsive to the strike and dip of the rocks. In these situations, perching of groundwater in the unsaturated zone is more common, and is typically associated with shaley beds. Fractures typically do not penetrate through an entire sequence of beds within the unsaturated zone. Therefore, the downward movement of groundwater will typically take on a stair-step pattern; moving down the length of a fracture, then moving down the dip of a bedding plane until another fracture is encountered.

3.6.0.3. The rate of infiltration of water through limestone in the unsaturated zone in karst environments varies greatly. In areas where the limestone contains insoluble clastic material, there may be a well defined C-horizon of rubbly material. In areas of more pure limestone and dolomite, such as at RAAP, the soil bedrock contact is typically very sharp. This is because the limestone and dolomite rubble is rapidly leached from the soil (White, 1990). The bedrock surface is typically sculptured into an elaborate network of joints widened by solution and small channels along bedding planes. The top few meters of these solution openings are usually filled with soil and provide a permeable zone for temporary storage of perched groundwater. After a rain event, groundwater may be held up in this region of the unsaturated zone for a period of days or weeks. If the soil becomes saturated with respect to calcite in the reaction zone at the base of the soil, it will move into the subsurface through fractures and joints with little additional reaction with the wall rocks. Joints and fractures carrying calcite saturated waters will only be slightly enlarged (White, 1990). Waters undersaturated with respect to calcite will enlarge the pathways while maintaining the overall geometry of the original joints and bedding plane sets. The width of the openings varies from less than a centimeter to greater than 2 meters.

3.6.0.4. The groundwater flow rate in karst aquifiers is generally much faster than in other types of aquifiers. Two types of flow can occur within karst aquifiers; conduit flow and diffuse flow. These two flow types are end members of a continuum; flow within most portions of a karst aquifier include some combination of each. Conduit flow is turbulent and includes groundwater flow through open cavities. Because this type of flow responds rapidly to rainfall and has a high ratio between the maximum discharge and the base- flow discharge (typically 10:1 to 1000:1), it is termed "flashy." Waters within conduit flow have low, but highly variable hardness. The turbidity, discharge and temperature of these waters also is highly variable. In less developed karst aquifiers, diffuse flow is more common. Diffuse flow involves groundwater flow through poorly integrated pores, joints and tubes within the rock. The discharge from karst aquifiers that have a substantial amount of diffuse flow responds slowly to rainfall. These aquifiers have a low ratio between maximum and base-flow discharge, typically 4:1 or less. Diffuse flow is generally laminar. The hardness of waters from diffuse flow is higher than for conduit flow. Also, the hardness, turbidity, discharge and temperature are less variable in diffuse flow (Quinlan, 1990).

3.6.0.5. The water table level in karst aquifers is strongly controlled by the elevation of the springs to which the aquifer is discharging. The spring elevation is typically

controlled by an entrenched river, as the New River does at RAAP. The solution conduits which feed the spring are typically so efficient in transmitting water, that they possess a low hydraulic gradient. Often, the potentiometric surface within or above the conduits lies only slightly higher than the spring elevation. During low flow, hydraulic heads in the large conduits are typically lower than the heads in the surrounding smaller and less efficient fractures. Therefore, water flows towards the conduit from the surrounding narrow fissures and pores. This trend is often reversed during flood conditions, when large openings are subjected to sudden surges of water from the surface (Palmer, 1984). The groundwater table in most karst regions is highly irregular and discontinuous, due to the great variation in the characteristics of the underground openings. Within most karst aquifers, conduits tend to form a branching system in which tributaries join to form larger passages with larger discharge. A karst aquifer can be viewed as an elaborate underground plumbing system through which water flows in discrete conduits. Water may stand at different elevations in nearby wells, and dry or poorly productive wells may occur in the same area as successful wells (Palmer, 1990). Because of these and other complexities apparent in karst aquifers, some researchers deny the existence of a karst water table. However, perched zones and water table irregularities apparent in karst aquifers are also observed in other aquifer types. These irregularities are more pronounced and on a larger scale in soluble rock than in other materials. Therefore, the water table concept can be valid for karst regions, but only if applied regionally rather than on the scale of individual solution conduits or wells (Palmer, 1990).

3.6.0.6. It is difficult to define the water table and the available supply of groundwater at RAAP. Several borings and groundwater monitoring locations within the Horseshoe Area indicate that the water table within the floodplain is approximately the same elevation as the surface water of the New River. These conditions also exist in the floodplain across the river in the Main Manufacturing Area of RAAP. In areas of high elevation within the Horseshoe and Main Manufacturing Areas, the water table is extremely variable. Because of impervious layers, solution cavities, and the thickness of overburden, extreme caution must be exercised in projecting water table data from existing groundwater monitoring locations into areas for which no groundwater data exist. The limestone and dolomite underlying RAAP is fractured, foliated, and faulted as a result of Paleozoic deformation. Topographic maps of RAAP show evidence of solution cavities and collapse structures (sinkholes) oriented along bedding planes within the less competent limestone units (Figure 3.10). There is a significant potential for movement of water through these features;

generally in an east-west direction. However, the groundwater flow direction is dependent on groundwater gradient which is generally directed toward the New River.

3.6.0.7. Groundwater levels in the bedrock aquifer generally respond to heavy precipitation within approximately 14 hours and may rise several feet in a short time (Engineering-Science, 1994b). This situation demonstrates that the karst aquifer underlying RAAP is characterized primarily by conduit flow and illustrates the direct connection between the groundwater and surface water that could impact the quality of groundwater for domestic use. The condition exists throughout RAAP, especially in areas where surface water infiltrates through sinkholes. Stormwater typically flows to the bottom of the sinkholes and rapidly travels downward through conduits into the unconfined aquifer. The New River appears to be the discharge area for groundwater at RAAP as well as for the regional groundwater. Open fractures and karst structures beneath the soil mantle coupled with the relatively low elevation of the New River (1,680 feet msl), provide accessible conduits for groundwater flow, thereby rapidly draining the overlying, less permeable soils (Charles T. Main of Virginia, 1988).

3.6.0.8. It is not completely understood how the Pulaski Fault, present at the facility, affects groundwater movement. The fault is not a simple planar feature, but rather a zone of regional deformation. At some areas, the location of the fault surface can be identified by the presence of lithologic unconformities. However, at RAAP and most other localities, the proximity of the fault surface is generally indicated by the abundance of the Max Meadows tectonic breccia. This breccia displays distinct weathering characteristics that appear to be the result of intergranular dissolution. As shown in Figure 3.6, the breccia develops extensive solution cavities which can allow for rapid conduit flow of the groundwater.

3.6.0.9. A dye-trace study conducted by Parsons ES (May 1994) identified a specific flow path connecting injection point 1 in SWMU 17 to a spring (sample SPG 3) discharging to the New River (Figure 3.10). This flow path closely parallels a series of west-northwest to east-southeast trending fracture traces and acts as a direct conduit for groundwater migration. This conduit was most likely created by solution openings along subsurface fractures. A more detailed discussion of groundwater conditions is included within each specific SWMU section of the report.

3.6.0.10. Water levels from 80 monitoring wells throughout RAAP are measured during quarterly sampling events at this facility. Table 3.7 summarizes groundwater elevation data collected during the 1995 first quarter sampling event. These data were used to develop a facility-wide groundwater gradient map (Plate 2). Some wells at this facility display unusually shallow or deep water levels compared with other nearby wells. These wells possibly intercepted perched groundwater zones or are influenced by karst features, such as sinkholes or conduits, which exert a strong local influence and are not reflective of the overall unconfined water table. Groundwater flow is generally towards the New River and away from areas of higher elevation.

3.6.0.11. Groundwater supplies in the Valley and Ridge province are presently of good or superior quality compared to surface water supplies. However, due to extended contact with minerals, many groundwater supplies contain higher levels of dissolved solids than the streams into which they discharge. Because of the sinkholes and underground caverns in karst aquifers, there is a potential for groundwater to be impacted by direct infiltration of contaminated surface water.

3.7 SURFACE WATER HYDROLOGY

3.7.0.1. The New River is the most significant surface water feature within RAAP. The facility is built within and adjacent to a prominent meander loop of this river. Within RAAP, the river width varies from 200 to 1,000 feet, but averages approximately 400 feet. The river flow varies due to water management at Claytor Dam, approximately 9 miles upgradient (south) from RAAP. Downstream from the Claytor Dam, typical flows of the New River range between 3,200 and 8,000 million gallons per day (mgd). During typical flow conditions, the depth is approximately 4 to 6 feet; however, pools may be 10 feet deep. There are 13 miles of river shoreline within the RAAP boundaries.

3.7.0.2. The headwaters of the New River are in northwestern North Carolina, near the Tennessee state line. In the vicinity of RAAP, the New River flows northwesterly cutting cliffs through the bedrock. The path of the New River, which is generally perpendicular to the ridge lines of the Valley and Ridge province, indicates that the river existed prior to the Paleozoic folding of these rocks. In some areas, this river has eroded 4000 feet of rock. During the Paleozoic, the erosion rate of the river was higher than the

TABLE 3.7
GROUNDWATER ELEVATION SUMMARY
RADFORD ARMY AMMUNITION PLANT

SWMU	WELL ID	Ground Elevation*	Groundwater Elevation*	Date
4	P-3	1752.56	1747.54	1/4/95
4	WC9B	1726.50	1711.22	1/4/95
4	WC8B	1740.14	1730.03	1/4/95
4	W4B	1727.50	1707.55	1/4/95
4	MW7	1722.50	1711.52	1/4/95
4	W2B	1733.50	1714.57	1/4/95
4	WC2-1	1735.40	1714.41	1/4/95
4	WC2-2	1735.40	1717.32	1/4/95
4	WC2-3	1735.40	1718.15	1/4/95
4	WC3-2	1726.50	1707.12	1/4/95
4	WC4-1	1713.50	1705.22	1/4/95
4	WC4-2	1713.50	1701.05	1/4/95
4	WC4-3	1713.50	1705.26	1/4/95
4	W5A	1715.40	1700.43	1/4/95
4	W6A	1714.20	1699.82	1/4/95
4	W7A	1705.00	1695.50	1/4/95
5	W8B	1787.58	1769.46	1/12/95
5	W5B	1773.13	1759.07	1/12/95
5	W7B	1772.78	1762.24	1/12/95
5	5WC2-1	1768.80	1759.01	1/12/95
5	5WC2-2	1768.80	1758.97	1/12/95
5	5WC2-3	1768.80	1759.37	1/12/95
5	S5W5	1769.81	1760.40	1/12/95
5	S5W6	1769.42	1760.44	1/12/95
5	S5W7	1773.08	1761.92	1/12/95
5	W9A	1761.10	1755.97	1/12/95
5	W10A	1768.40	1753.72	1/12/95
5	W11A	1764.70	1750.46	1/12/95
7	W12B	1714.81	1691.61	1/20/95
7	7WCA	1712.40	1690.13	1/20/95
7	W11B	1712.90	1690.47	1/20/95
7	MW5	1713.20	1690.26	1/20/95
7	MW6	1712.80	1688.34	1/20/95
7	S7W9	1710.48	1686.86	1/20/95
7	W9C	1703.70	1689.44	1/20/95
7	W11	1712.82	DRY	1/20/95
7	W10B	1704.65	1690.93	1/20/95
7	W10C	1707.50	1687.90	1/20/95
10	DG-1	1709.96	1689.95	3/1/95
10	DDH4	1713.16	1690.30	3/1/95
10	D4	1713.42	1692.65	3/1/95
10	DDH2	1700.78	1686.66	3/1/95
10	D3	1700.51	1685.25	3/1/95
10	D3D	1700.70	1685.77	3/1/95
10	10MW1	1701.28	1685.96	3/1/95

* FEET ABOVE MEAN SEA LEVEL

TABLE 3.7
GROUNDWATER ELEVATION SUMMARY (CONTINUED)
RADFORD ARMY AMMUNITION PLANT

SWMU	WELL ID	Ground Elevation*	Groundwater Elevation*	Date
13	13MW1	1698.66	1680.71	2/14/95
13	13MW2	1701.21	1681.87	2/14/95
13	13MW3	1693.41	1681.38	2/14/95
13	13MW4	1695.18	1679.52	2/14/95
13	13MW5	1695.26	1679.73	2/14/95
13	13MW6	1693.81	1679.44	2/14/95
13	13MW7	1693.81	1679.78	2/14/95
16	C1	1836.78	1788.83	1/26/95
16	MW8	1815.82	1744.77	1/26/95
16	MW9	1808.88	1745.83	1/26/95
16	WC1B	1812.95	1745.33	1/26/95
16	WC1A	1812.61	1745.26	1/26/95
16	16-1	1813.88	1764.97	1/26/95
16	16-2	1808.78	1754.53	1/26/95
16	16-3	1823.83	1767.71	1/26/95
16	16-5	1739.50	1737.75	1/26/95
16	WC2A	1818.05	1755.83	1/26/95
16	WC2B	1818.71	1765.61	1/26/95
16	C3	1819.22	DRY	1/26/95
17	17PZ1	1904.70	1800.14	1/17/95
17	17MW2	1903.99	1799.35	1/17/95
17	17MW3	1904.27	1760.59	1/17/95
17	40MW2	1881.10	DRY	1/17/95
17	40MW3	1856.02	1763.83	1/17/95
17	40MW4	1906.10	DRY	1/17/95
26B	B2	1759.47	1682.42	2/24/95
26B	B3	1765.09	1692.72	2/24/95
26B	B4	1764.64	1695.88	2/24/95
26B	BDH3	1822.55	1741.34	2/24/95
31	31MW1	1713.45	1682.68	1/17/95
31	31MW2	1697.49	1679.43	1/17/95
31	31MW3	1697.20	1680.82	1/17/95
31	31MW4	1697.14	1678.40	1/17/95
48	48MW1	1817.79	1713.25	1/18/95
48	48MW2	1817.62	1701.39	1/18/95
48	48MW3	1809.96	1719.46	1/18/95
74	74MW1	1732.60	1710.41	2/3/95
74	74MW2	1803.10	1747.89	2/3/95
74	74MW3	1729.60	1710.38	2/3/95
74	74MW4	1728.80	1706.47	2/3/95
74	74MW5	1736.50	1712.02	2/3/95
74	74MW6	1731.40	1708.56	2/3/95
74	74MW7	1730.90	1707.81	2/3/95
FAL2	FAL2	1756.13	1723.54	2/23/95
FAL2	FAL3	1757.43	1691.35	2/23/95
FAL2	WELL7	1823.03	1798.66	2/23/95

* FEET ABOVE MEAN SEA LEVEL

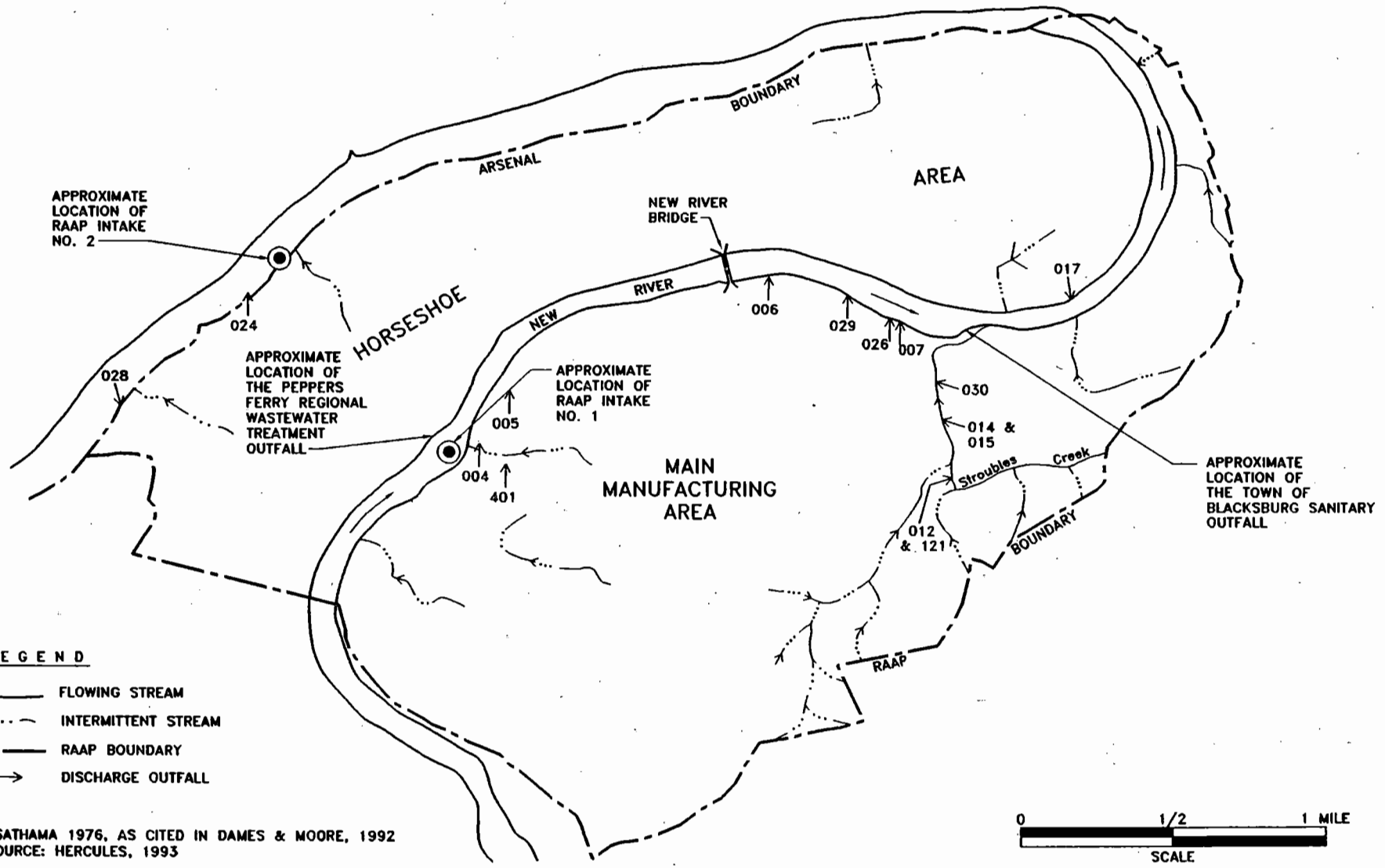
uplift rate of the rocks. This produced the entrenched river channel present today. The New River is perhaps the oldest river in North America, estimated to be 350 million years old

3.7.0.3. Stroubles Creek is the largest local tributary of the New River and flows through the southeast sector of RAAP. This creek is fed by several branches that originate on and off the facility. The larger surface drainage ways within the installation and their direction of flow are shown in Figure 3.11. Manmade surface drainage ways at RAAP also influence local drainage. The direction of all surface drainage flow within RAAP is ultimately toward the New River.

3.7.0.4. Stroubles Creek consists primarily of stormwater runoff. Groundwater discharging from the karst bedrock may also supply significant stream flow. Prior to entering the facility, branches of Stroubles Creek flow through rural areas and through the City of Blacksburg. The creek empties into the New River within RAAP and contributes significant loading of domestic and industrial wastewater (USATHAMA, 1976). The Blacksburg Municipal Wastewater Treatment Plant discharges approximately 5.7 mgd of water into the New River just upstream of where Stroubles Creek empties into the river (Personal Communication with R. Graham at Peppers Ferry Wastewater Treatment Plant, 1995). The Commonwealth of Virginia has classified Stroubles Creek and the portion of the New River passing through the confines of RAAP as water generally satisfactory for beneficial uses; these include, public or municipal water supply, secondary contact recreation, and propagation of fish and aquatic life (USATHAMA, 1976).

3.7.0.5. All water used at RAAP is taken from the New River. Separate water systems are provided for the Main Manufacturing Area and the Horseshoe Area. Intake No. 1 is located approximately 2 miles upstream of the mouth of Stroubles Creek. Intake No. 2 is located approximately 6 miles downstream of the mouth of Stroubles Creek (Figure 3.11). Upstream of RAAP, the New River serves as a source of drinking water for the towns of Blacksburg and Christiansburg.

FIGURE 3.11
SURFACE WATER DRAINAGE/OUTFALL LOCATIONS
RADFORD ARMY AMMUNITION PLANT
RADFORD, VIRGINIA



SOURCE: USATHAMA 1976, AS CITED IN DAMES & MOORE, 1992
OUTFALL SOURCE: HERCULES, 1993

17702-9 9/7/95

3.7.0.6. Both industrial and domestic wastewaters are discharged into the New River from the Peppers Ferry Regional Wastewater Treatment Plant (PFWWTP). This discharge is located within RAAP, just downstream from intake No. 1. Until 1987, the city of Radford provided only primary sewage treatment before discharging 2.5 mgd into the New River (USATHAMA, 1976). Secondary treatment is now provided at the PFWWTP. Currently this plant discharges approximately 4.5 mgd of water into the New River (Personal Communication with R. Graham at PFWWTP, 1995).

3.7.0.7. RAAP discharges approximately 25 mgd at fifteen industrial wastewater outfalls along the New River and Stroubles Creek under VPDES permit number VA0000248. The effluent consists of various treated process water, wash water, cooling water, run off, sanitary wastewater, and stormwater. The approximate locations of the discharge outfalls are shown in Figure 3.11. For internal use and reference, RAAP has identified a total of 135 outfalls to either the New River or Stroubles Creek from the Main Manufacturing and Horseshoe Areas. These outfalls discharge stormwater, spring-fed groundwater, and minor amounts of steam condensate.

3.7.0.8. The New River itself has experienced few major problems from the discharge of either treated or untreated effluent. The ability of the New River to recover from organic loading is generally high because of the river's natural reaeration characteristics, high base flow, and the present quality and quantity of waste discharge.

3.7.0.9. The upper reaches of the New River and its tributaries have water of excellent quality. These streams have less than 50 parts per million (ppm) of dissolved solids due to the underlying metamorphic rocks, which contribute very little to natural pollution. In the balance of the region, dissolved solids increase to the 50 - 199 ppm range as water drains from areas underlain by shale, sandstone, and limestone formations. Where carbonate rocks occur, the bicarbonate content of the water is particularly high, resulting in 100 - 199 ppm of calcium carbonate ($CaCO_3$) found in the waters of Walker Creek, Sinking Creek, Wolf Creek, and the New River downgradient of RAAP (Figure 2.2).

3.8 GROUNDWATER USAGE

3.8.0.1. Private and public groundwater wells are used in the vicinity of RAAP for drinking water and other domestic and agricultural purposes. A document search to identify

private water well use within one mile of the RAAP property line was conducted as part of the current investigation to determine the extent of private water well use in this area (New River Health District, 1995). Since September 1, 1990, a total of 36 property owners living within 1 mile of RAAP applied for a permit through the appropriate County Health Department to construct individual water supply wells. These property owners primarily reside in the following developments; the River Bluffs subdivision and along gate ten road in Pulaski County and in the regions of Prices Fork, Longshop and McCoy in Montgomery County. The names and addresses of these property owners is given in Appendix B. Prior to September 1, 1990, property owners were not required to obtain Health Department approval prior to well installation. Therefore, it is estimated that 50 percent or more of the existing residents within one mile of RAAP have private water supplies (i.e. cisterns, springs, wells, etc.) for which the Health Department has no record (New River Health District, 1995).

3.8.0.2. In addition to the private water supply wells in the vicinity of RAAP, 14 public water supply wells have been identified within three miles of the RAAP boundary. Public water supply wells service more than 15 people and are regulated through the Virginia State Department of Health. The location of these supply wells is given in Appendix B. Plates 3A and 3B display the locations of the public water supply wells and the area utilizing private wells in the vicinity of RAAP.

3.8.0.3. For domestic purposes, most residents in the vicinity of RAAP utilize surface water supplied primarily by the water treatment plant at Claytor Dam. Areas on public water include the City of Radford, Fairlawn, and properties along Route 114 in Montgomery County.

3.8.0.4. Two groundwater supply wells are present on the RAAP facility. However, neither of these wells is currently being used for any purpose. Those well locations are shown on Plate 1.

3.9 ECOLOGY

3.9.0.1. The last comprehensive inventory of the mammals, birds, reptiles, aquatic invertebrates, trees, and plants found on the installation, and of the fish inhabiting the New River where it flows through the installation was conducted in 1976 during an installation

assessment of RAAP (USATHAMA, 1976). Information from that assessment was summarized in previous documents (Dames & Moore, 1992a and 1992b). The summarized information was updated through personal communication with RAAP biologists and is presented in the following paragraphs.

3.9.0.2. Many of the reptiles, mammals, and birds listed in the 1976 Installation Assessment (USATHAMA, 1976) are believed to breed on the installation (Personal Communication, 1995). However, indications are that some species, including ruffed grouse and upland plovers, have decreased in number or have disappeared from RAAP (USATHAMA, 1976). Foxes which were once trapped to prevent rabies outbreaks have recently been reintroduced to RAAP as a control for groundhogs. Deer are common at RAAP and bow hunting has been allowed at the facility since 1991. Migratory waterfowl are found throughout the spring and winter near the New River because the installation is on the Atlantic Flyway. Federally protected black vultures are present at RAAP during certain times of the year. Between 1,500 and 3,000 of the migratory birds nest in thickets on the facility (Washington Post, 1995). Fishing occurs in the New River which flows through RAAP.

3.9.0.3. No threatened or endangered species have been found at RAAP. However, six endangered plant species, three threatened plant species, one endangered mollusk species, one threatened mollusk species, one endangered insect species, four threatened insect species, three endangered bird species, and the locally endangered mountain lion have been identified for Pulaski and Montgomery Counties by the Virginia Department of Game and Inland Fisheries. In addition, a fish, salamander, four bird species, and the river otter are identified as species of special concern in the two counties in which RAAP is located.

3.9.0.4. According to the RAAP Installation Assessment (USATHAMA, 1976), timber harvesting occurred on RAAP in the past. The most recent harvest was conducted in 1987. Tree species at RAAP include the shortleaf pine, loblolly pine, eastern white pine, yellow poplar, and black walnut. There are 2,537 acres of managed woodland on site (Personal Communication with T. Thompson RAAP Conservation Specialist, 1995). No reforestation has occurred in the Main Manufacturing Area. In 1964, 922 acres of the Horseshoe Area were reforested.

SECTION 4

FIELD INVESTIGATION PROGRAM

4.1 OVERVIEW

4.1.0.1. The RCRA Facility Investigation field program was conducted during December 1994 and January 1995. USEPA comments suggested the need for additional investigative tasks which were not proposed in the RFI Work Plan (Engineering-Science, Inc., 1994a), including more sampling of existing wells, a soil background metals study, further characterization of the New River, and installation of an additional monitoring well at SWMU 48. These tasks were completed in July 1995. The field work included: monitoring well installation and development; soil boring completion; staff gauge installation; sampling of surface soils, sediments, surface water, groundwater, and waste piles; completion of a soil background metals study; and the performance of aquifer testing. The dye-tracing study for SWMU 17/40, which was conducted during the fall of 1993 and the spring of 1994, and which was submitted as a separate report, has been summarized in this document.

4.1.0.2. The field investigation program provided data to supplement existing information necessary to fully characterize SWMUs 17/40, 31, 48, and 54. Additionally, information was obtained which applies to the site-wide characterization of the facility. In particular, the New River sampling and the soil background metals investigation, provided data which can be used to address information gaps and identified deficiencies in the prior assessments of many of the SWMUs at RAAP. The work activities were completed in accordance with the RFI Work Plan and Quality Assurance Project Plan (Engineering-Science, Inc., 1994c), the Dye-Tracing Study Work Plan (Engineering-Science, Inc.,May 1993), and the Revised Addendum to the RFI Work Plan (Parsons ES, June 1995) to ensure that usable data of known and acceptable quality were generated. This section presents a general description of the field investigation program activities. More detailed information, such as sample locations and SWMU site plans, is included in each SWMU-specific section. The results of the field investigations decribed here are presented in subsequent sections of the report.

4.2 DRILLING PROCEDURES

4.2.0.1. A total of 43 soil borings and eight monitoring wells were completed during the investigation. Eighteen of the 43 soil borings were installed for the soil background metals study. All drilling was directed by an experienced geologist who prepared a detailed lithologic log using the Unified Soil Classification System (USCS). The lithologic logs and well construction diagrams are presented in Appendix C.

4.2.1 Soil Borings

4.2.1.1. Seven soil borings were advanced to the overburden-bedrock interface at various areas of SWMU 17 to characterize the vertical extent of contamination present. The borings were installed by hollow stem auger drilling methods. A truck mounted drilling rig (B80/92) used 4.25 inch (inside diameter) hollow stem augers to penetrate the unconsolidated material to depths of approximately 28 feet below ground surface in two filled-in sinkholes at SWMU 17. Soil samples were collected with split spoon devices at 5 foot intervals using the Standard Penetration Test (ASTM D-1586). Unless subsurface conditions (cobbles or gravel) caused minor deviations from the Work Plan, the samples were collected in 2 foot long spoons with the bottom depths in multiples of 5 feet (e.g., 3-5 feet, 8-10 feet).

4.2.1.2. All downhole equipment (augers, spoons, rods, and bits) was decontaminated by steam cleaning prior to starting a new drilling location. The spoons were decontaminated by washing with an Alconox solution followed by a methanol rinse and then a final deionized water rinse. All soil borings were backfilled by tremie pipe with a grout consisting of cement, bentonite powder, and USAEC approved water.

4.2.1.3. Two soil borings were advanced in the SWMU 48 disposal areas. At these locations, a continuous sampling spoon (Moss Sampler) was used at shallow depths to allow a more detailed examination of the soils for visual signs of hydrocarbon contamination. The Moss Sampler took continuous soil samples in 5 foot intervals (0-5 feet, 5-10 feet) for the top 15 feet of the upper disposal area (48SB4) and the top 10 feet of the lower disposal area (48SB5). The remainder of the holes, 21 feet and 37 feet total depths for 48SB4 and 48SB5, respectively, were sampled with standard split spoons in general accordance with the procedures described for SWMU 17. The geologist used field judgement based upon photoionization (PID) readings and visual observations to decide whether continuous or 5-foot spoons were necessary.

4.2.1.4. Sixteen soil borings were advanced at SWMU 54 to bedrock (a maximum depth of 24 feet). Two of the borings, 54SB6 and 54SB14, were completed with the continuous Moss Sampler, the rest were sampled with standard split spoons at 5 foot intervals. 54SB6 was within the lower ash mound and 54SB14 was beside the upper ash mound.

4.2.1.5. Eighteen soil borings were completed for the soil background metals study using small diameter (3.5 inches) hollow stem augers. Samples were collected by continuous split spoon methods so that distinct B and C soil horizons could be identified. Minor modifications to the Work Plan were necessary due to auger refusal, insufficient sample recovery at the desired depth, or identification of the horizon at a depth different than that predicted in the Work Plan. Lithologic logs for the background borings are contained in Appendix C.

4.2.2 Monitoring Wells

4.2.2.1. Eight monitoring wells were installed at two SWMUs, four at SWMU 31 and four at SWMU 48. Well 48MW4 was installed in July 1995; the other seven were installed in December 1994/January 1995. All wells were begun using 6.63 inch inside diameter hollow stem augers (for 4 inch wells). However, where bedrock or tough subsurface conditions were encountered, air rotary methods (6 inch or 8 inch tri-cone rotary bits or a 10 inch air hammer) were employed.

4.2.2.2. At SWMU 31, two wells were installed with augers and two required air rotary techniques for completion. Soil sampling was conducted with split spoons at 5 foot intervals or less based on the geologist's judgement. One monitoring well boring, 31MW3, was sampled continuously with the Moss Sampler to provide detailed lithologic information for SWMU 31.

4.2.2.3. The four wells installed at SWMU 48 were relatively deep, ranging from 120 feet to 154 feet below ground surface, and required air drilling methods beginning at approximately 30 feet to 60 feet down. Soil samples of the overburden of each monitoring well boring were collected by split spoon methods. Temporary 10 inch casing was installed in 48MW2, 48MW3, and 48MW4, to prevent borehole collapse during air drilling.

4.3 MONITORING WELL COMPLETION PROCEDURES

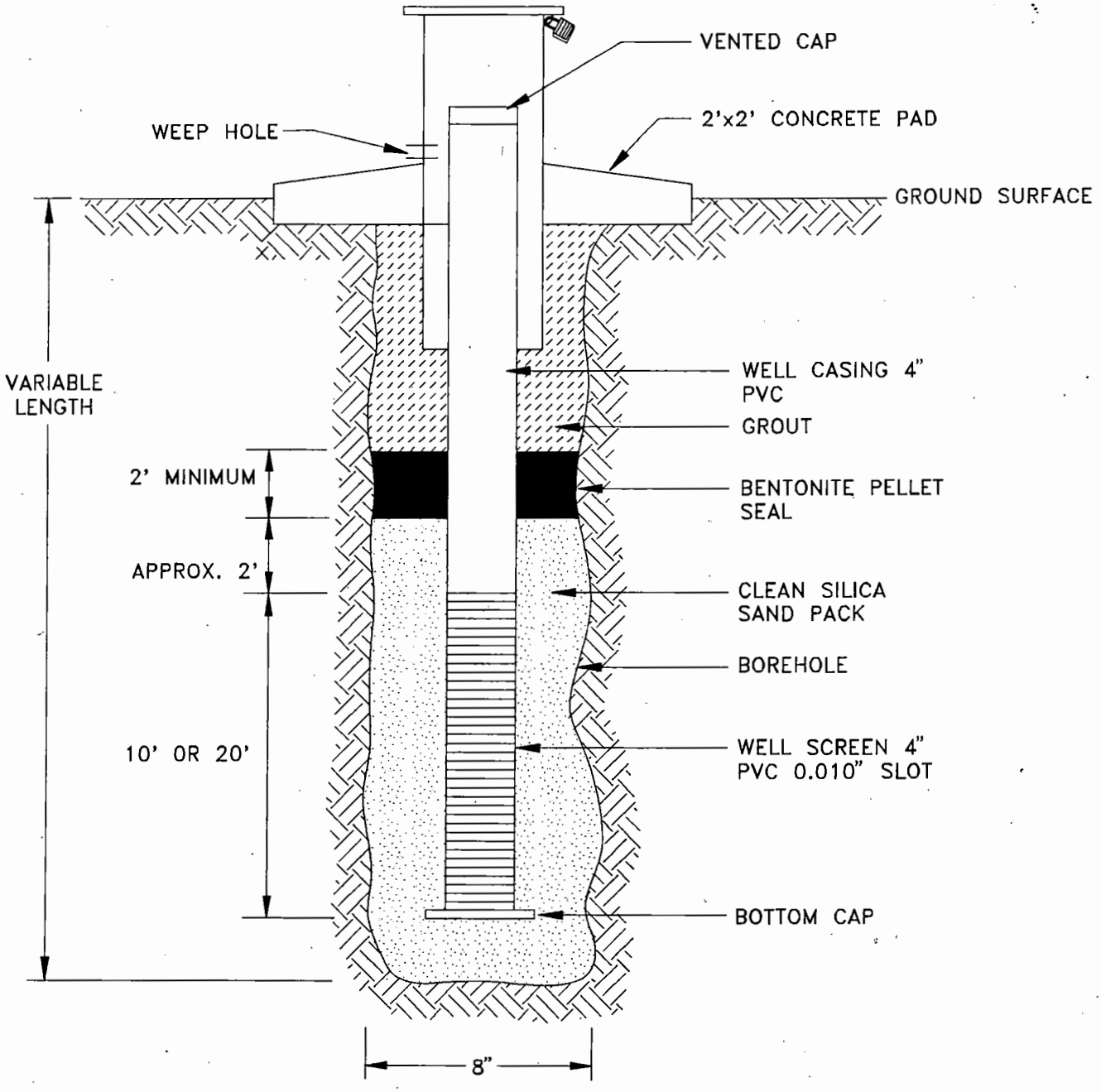
4.3.1 Monitoring Well Construction

4.3.1.1. All monitoring well construction procedures were in accordance with the USAEC's Geotechnical Requirements (USATHAMA,1987) and Commonwealth of Virginia guidelines. Unless otherwise noted below, the wells were constructed as follows: four inch (inside diameter) schedule 40 PVC pipe was installed inside the hollow stem auger; ten feet of 0.10 inch PVC slotted screen, plugged at the bottom, was used; threaded couplings joined the casing and screen; the top of the screen was positioned 1-2 feet above the stabilized groundwater level; the sand filter pack was extended to approximately two feet above the top of the screen; a five foot thick bentonite seal was placed above the filter pack; the remainder of the annulus was filled to ground surface with a cement-bentonite mixture by tremie pipe; the augers were removed slowly to allow settling of the grout; the PVC casing extended 2-3 feet above ground surface; a five foot long, six inch diameter steel casing was installed over the PVC casing; and four steel protective posts were placed around the well. Filter pack sand size and screen slot size were based upon geotechnical data from the applicable geologic formations obtained during previous investigations (Dames & Moore, 1992a and 1992b). A construction diagram of a typical monitoring well is presented as Figure 4.1. Table 4.1 lists the construction details of the eight new wells and the existing wells sampled during this investigation.

4.3.1.2. The wells installed at SWMU 48 were deeper and more difficult than those at SWMU 31. Therefore, some deviations from the Work Plan procedures were necessary. The wells were installed inside temporary steel casings since the hollow stem augers were not large enough to fit some of the air rotary equipment used to penetrate the bedrock. Greater screen lengths were used because of the difficulty of predicting groundwater movement in the bedrock. Since the potential for floating hydrocarbon compounds existed at this SWMU, it was important to position the screen to intercept these compounds. Because the bedrock was relatively tight and the groundwater stabilized level could not be predicted, a 30 foot long screen was installed in the first well drilled (48MW1) at this SWMU. Once the general groundwater level was established, 20 foot screens were used in the three remaining SWMU 48 wells.

FIGURE 4.1
TYPICAL MONITORING WELL CONSTRUCTION

RADFORD ARMY AMMUNITION PLANT
RADFORD, VIRGINIA



22843WEL 10/23/95

TABLE 4.1

MONITORING WELL CONSTRUCTION DETAILS

RADFORD ARMY AMMUNITION PLANT
RADFORD, VIRGINIA

Well Name	Well Depth (ft)	Well Elevation At T.O.C. (ft)	Depth To Water (ft)	Water Elevation (Ft)	Screen Length (Ft)	Well Diameter (In)
31MW1	52.40	1715.04	34.43	1680.61	10	4
31MW2	28.50	1699.05	25.82	1673.23	10	4
31MW3	32.43	1698.82	25.04	1673.78	10	4
31MW4	30.45	1698.55	24.92	1673.63	10	4
48MW1	142.00	1819.95	103.86	1716.09	30	4
48MW2	135.70	1818.88	123.86	1695.02	20	2
48MW3	122.30	1812.17	94.46	1717.71	20	4
48MW4	96.06	1832.60	78.30	1754.30	20	4
17MW2	173.00	1906.29	99.76	1806.53	20	4
17MW3	181.50	1906.78	146.91	1759.87	20	4
40MW3	120.00	1858.21	94.44	1763.77	20	4
17PZ1	132.50	1907.02	99.69	1807.33	20	4
40MW2	60.00	1882.51	DRY	DRY	20	4
40MW4	62.80	1908.11	DRY	DRY	20	4
54MW1	52.00	1707.78	18.70	1689.08	20	4
54MW2	28.00	1701.41	22.60	1678.81	10	4
54MW3	30.00	1702.15	23.81	1678.34	10	4

NOTES:

1. Water elevations were taken in July 1995.
2. All wells were constructed of PVC materials.
3. Well name includes the SWMU designation.
4. Elevations are in feet above mean sea level.
5. The SWMU 31 and 48 wells were installed by Parsons ES in January or July 1995; 17MW2, 17MW3, and 40MW3 were installed by Parsons ES in May 1993; the other wells were installed by Dames & Moore in 1991-1992.

4.3.1.3. 48MW2 was completed as a two inch inside diameter well. Drilling difficulties encountered while attempting to install this well included a "dogleg" caused by particularly soft overburden on top of relatively hard bedrock, and a collapsing borehole as downhole equipment tried to negotiate the "dogleg." In order to save the hole, and avoid redrilling approximately 80 feet of overburden and bedrock, a two inch well, which was not obstructed by these conditions, was installed.

4.3.2 Monitoring Well Development

4.3.2.1. Well development procedures were slightly modified from the Work Plan description based on comments from the USEPA. Wells installed by Parsons ES were developed by pumping which was initiated at least 48 hours but no longer than seven days after completion of the well. The entire water column was evacuated by periodically changing the position of the submersible pump during development. At least six well volumes of groundwater were removed. This included the column of static water and the saturated annulus outside of the screen.

4.3.2.2. Monitoring of the physical and chemical characteristics of the groundwater, including, pH, conductivity, temperature, color, odor, and turbidity, was performed throughout the development procedure. After removal of six volumes of groundwater from each well, development continued until pH, conductivity, and temperature readings were reproducible within 20 percent of the prior set of readings. The field data sheets containing the development information are presented in Appendix D.

4.3.2.3. In general, the wells at SWMU 31 were slow in recharging; the bedrock wells at SWMU 48, with the exception of 48MW2, were relatively quick rechargers. The groundwater from all wells was visually clear after completion of development.

4.4 SOIL BACKGROUND METALS STUDY

4.4.0.1. The soil background metals study was conducted in response to USEPA comments concerning inorganic concentrations present in site background soils. The objective of the study was to establish statistically valid background levels of metals in the soil as the basis for comparisons between those levels and concentrations of metals found in the SWMUs.

The sampling methodology and statistical analysis summarized below were in accordance with the approved Revised Addendum to the Final RFI Work Plan (Parsons ES, June 1995).

4.4.0.2. In order to establish background soil metals concentrations which could be compared to all soil sampling for metals at any SWMU on the facility, a review of the previous soil sampling procedures was undertaken. It was determined that only three of the ten identified soil types (SCS 1985a, 1985b) across the facility were actually sampled during previous and current investigations. The review also took into account sampling procedures and depths of the previous investigations to ensure that similar samples would be collected during the background study for comparison.

4.4.0.3. The B and C horizons of the three soil types, taken at various depths, were sampled from background areas across the site. Designations of background areas were based on distance from SWMUs or impacted areas, facility history or personnel interviews, and field reconnaissance. Eighteen borings and 36 samples were collected (as described in 4.2 above) and submitted for metals analyses.

4.4.0.4. The data then underwent statistical testing in accordance with the Work Plan. The results are presented in the baseline risk assessment (Section 6).

4.5 DYE TRACING STUDY

4.5.0.1. The dye tracing test was conducted at SWMU 17 in the Fall of 1993 and the Spring of 1994. The Work Plan was completed in May 1993 and the Dye-Tracing Study Report was submitted in March 1994 and amended in September 1994 (Parsons ES, September 1994). This subsection is a summary of the field procedures for the test. The test findings are discussed in the SWMU 17/40 section.

4.5.1 Well Installation

4.5.1.1. As part of the dye-tracing study, three bedrock monitoring wells and two temporary dye-injection wells were installed in the SWMU 17 area. The bedrock wells ranged in depth between 120 feet and 190 feet and were designed to intercept the regional water table associated with the New River. The two dye-injection wells, located in the two

major sinkholes of SWMU 17, were installed to a maximum depth of 23.5 feet. The orientation of the injection wells to the New River receptor is shown in Figure 3.10.

4.5.1.2. The bedrock borings were advanced using air-hammer drilling techniques. Prior to well placement, a color television camera was lowered into each borehole to facilitate examination of structural features (bedding planes and fractures) and physical condition (solution features). The wells were then constructed in the borehole with 4-inch inner diameter, flush-joint, schedule 40 PVC pipe and screened over the lower 20 feet.

4.5.1.3. The two temporary dye-injection wells (INJ1 and INJ2) were installed in the southwest corner of the Stage and Burn Area (SWMU 17A) and adjacent to the Runoff Drainage Area (SWMU 17E). The borings were advanced using either air rotary or hollow stem augers drilling methods and were designed to extend through the soil fill material in the bottom of the sinkhole to the bedrock interface. The injection wells were constructed with an open ended 4-inch, inner diameter PVC pipe.

4.5.2 Dye Selection

4.5.2.1. Sodium Fluorescein, Rhodamine WT, and Direct Yellow 96 dyes were chosen for this study. Fluorescein (CI Acid Yellow 73) is a green fluorescent dye that is recovered on activated coconut charcoal. Direct Yellow 96 is a yellow fluorescent dye recovered on unbleached, unwhitened cotton detectors. Rhodamine WT is a pink fluorescent dye recovered on activated coconut charcoal.

4.5.3 Dye Injection

4.5.3.1. Prior to injecting the dye for this study, field reconnaissance activities were conducted of the study area between late May 1993 to early June 1993. These efforts were conducted to locate and verify dye monitoring points and to locate additional monitoring points not previously identified in the Work Plan. During field reconnaissance for the final selection of dye monitoring locations, dye-detector 'bugs' were placed in all prospective monitoring locations that were to be utilized during the dye-trace test. They were retrieved prior to dye injection and tested for background levels of Fluorescein and Direct Yellow dyes. A total of 35 monitoring locations were chosen for the initial dye injections that took place in the fall of 1993. Of these, 27 monitoring locations were used for the second dye

injection in the spring of 1994. Approximately one week prior to the second injection, dye-detector 'bugs' were placed at each of the prospective monitoring locations. These bugs were retrieved prior to dye injection and tested for background levels of Rhodamine WT dye.

4.5.3.2. During the initial stage of this investigation, the dyes were introduced on September 23, 1993 during relatively low flow conditions after a storm event. Fluorescein dye was injected into INJ1, located in SWMU 17A. Prior to introduction of the dye, approximately 1,200 gallons of unchlorinated water was pumped into the injection well to saturate the potential flow pathways. The dye was then introduced directly into the well after the slug of water infiltrated into the sinkhole. Following injection, the dye was followed by a chaser of 1,200 gallons of unchlorinated water injected at a moderate and constant rate.

4.5.3.3. A similar injection method was attempted at INJ2, located in the runoff drainage basin (SWMU 17E). Initially, unchlorinated water was pumped into the injection well; however, the water did not infiltrate into the surrounding formation. The remaining 1,150 gallons of water was pumped onto the ground surrounding the injection well in an effort to saturate the entire area. The Direct Yellow dye was then introduced into the well and also poured into the ponded water in the runoff basin. Another 1,200 gallons of unchlorinated water were pumped on the ground at the runoff drainage basin to further saturate the soil overburden and to speed up dye infiltration.

4.5.3.4. During the second stage of this investigation, Rhodamine WT dye was introduced on April 18, 1994 during relatively high flow conditions. Rhodamine WT dye was injected into INJ1, located in SWMU 17A. Prior to introducing the dye, approximately 1,250 gallons of unchlorinated water was pumped into the injection well to saturate the potential flow pathways. The dye was poured directly into the well, after the slug of water infiltrated the sinkhole. Following the injection of the dye, an additional 1,250 gallons of unchlorinated water was pumped into the injection well at a moderate and constant rate.

4.5.4 Dye Monitoring

4.5.4.1. Passive detectors, or "bugs," were used to accumulate dyes for visual examination during this investigation. Fluorometric techniques were used to detect the dye and to provide qualitative and/or semi-quantitative measures of the dye concentration. Visual

examination was chosen for this study in order to reduce the complexity of the detector processing while still meeting the objectives of the study. Activated charcoal was used to adsorb Fluorescein and Rhodamine WT dye for detection and Direct Yellow was detected on cotton bugs.

4.5.4.2. During both stages of this investigation, both a cotton and a charcoal bug were placed at each monitoring location. Although no dyes were injected in the spring of 1994 that would be detected on a cotton bug, these were used to examine if residual direct yellow dye remained in the groundwater. The bugs were suspended above the stream bed using a weighted, stable stand known as a "gumdrop." Detectors installed in wells were suspended below the water table by a piece of weighted polypropylene rope.

4.5.4.3. A total of 35 locations were monitored for the resurgence of dye during the initial stage of this investigation (15 stream locations, 9 river locations, 7 spring locations, and 4 well locations). A total of 27 locations were monitored for the resurgence of dye during the second stage of this investigation. Seven river monitoring points and one stream monitoring point (SMP 17) were dropped for the second stage of this investigation. These points were dropped based on findings of the initial dye injection which indicated that these were improbable discharge points.

4.5.4.4. During the field reconnaissance phase and prior to each dye injection, detectors were placed at each of the monitoring locations and tested for background levels of the dyes. During the tracing study, the bugs were collected from each monitoring location and analyzed for dye on a daily basis during the first week after dye injection. A biweekly monitoring schedule was implemented during weeks two through twelve of the initial stage of this study. A monthly monitoring schedule was implemented for weeks two through twelve during the second stage of this study. Both the charcoal and cotton bugs were collected from all locations during the monitoring program.

4.6 SURFACE WATER ELEVATION GAUGE INSTALLATION

4.6.0.1. Surface water elevation (staff) guages were installed in each of the three lagoons at SWMU 31, and initially in the New River just beyond the SWMU 31 boundary. The gauges consisted of calibrated steel posts driven by hand into the ground or sediment. The

gauges were surveyed to establish water elevations across the SWMU to complete a water balance study of the lagoons and river.

4.6.0.2. The staff gauge installed in the New River was washed away by flooding caused by a heavy rainfall event in January 1995. Therefore, a permanent structure, from which periodic river elevation measurements could be taken, was surveyed and used for the water balance study of the SWMU 31 lagoons. The structure was a concrete abutment at the facility's treatment plant. Measurements were taken with an electronic water level indicator.

4.7 AQUIFER TESTING

4.7.0.1 Slug injection and withdrawal tests were conducted at SWMUs 31 and 48 to determine hydraulic conductivity and transmissivity of the water-bearing strata. The slug tests were performed by subjecting the water-bearing unit in the screened interval of the well to a stress caused by a short-term injection or withdrawal of a known volume (slug). The response of the water-bearing units to the stress was measured by recording the water level rise or fall in the test well as it returned to equilibrium (pre-test) conditions.

4.7.0.2. Seven injection (falling-head) and three withdrawal (rising-head) tests were conducted at the two different SWMUs. Subsection 8.4.3.1 provides results from the four injection tests and two withdrawal test at SWMU 31. Subsection 9.4.3.1 provides results from the three injection tests and one withdrawal test at SWMU 48.

4.7.0.3. Initial static water levels were collected before testing took place. A data logger was then connected to a pressure transducer and placed at the bottom of the well. The water level was allowed to stabilize after insertion of the transducer; this new stabilized water level was recorded in a field log book and then input into the data logger before starting the slug test. Injection tests were performed by rapidly inserting the slug into the well followed by data logger and hand-measurements (for confirmation) of the subsequent water level changes until 98% of the pre-insertion static water level was attained. Withdrawal tests were then performed on the test well by rapidly removing the slug from the well column and monitoring the water level rise to within 98% of the static level, or a period of 24 hours was reached.

4.7.0.4. The slugs used for this investigation were five feet in length and constructed with 2-inch inner diameter PVC pipe. Clean #2 weight gravel pack sand was placed in the PVC pipe to ensure maximum water level displacement. The slugs and other downhole equipment were decontaminated in accordance with Work Plan procedures prior to and after each test to avoid cross-contamination.

4.7.0.5. Note that a modified version of the Work Plan specified procedure was used for the slug tests. The modification from pumping to slug injection was made to eliminate the need to containerize potentially contaminated groundwater.

4.7.0.6. There were two exceptions to the slug test procedures described above. Wells 31MW2 and 48MW2 were not tested using the five foot PVC pipe slugs. Well 31MW2 only contained 3.5 feet of water; the PVC slug would not have displaced a sufficient amount of water for the slug test. Therefore, five gallons of deionized water were added to the well to conduct a falling-head test. Because the water had to be poured into the well, hand-measurements of the water levels could not begin until 30 seconds after the data logger was started. Similarly, 48MW2 was not tested with a PVC slug. 48MW2 is constructed with a 2 inch PVC casing and that diameter is not large enough to accommodate the slug. Five gallons of deionized water were added to this well to conduct a falling-head test. Hand-measurements were taken approximately 40 seconds after the data logger was started.

4.7.0.7. The slug test data were analyzed using the Bouwer and Rice (1976) method. The fitting of data to an "S"-shaped type curve for the Bouwer and Rice straight line (1976) method permits the calculation of hydraulic conductivity and transmissivity for the formation surrounding the well screen. Type curves and calculation sheets are included in Appendix E.

4.8 SURVEYING

4.8.0.1. Surveying activities were completed by Geotrack, Inc., a firm licensed in the state of Virginia. Location coordinates of data points were established within 3.0 feet using the Virginia State Planar Coordinate System of 1927. Elevations were established within 0.01 feet using the National Geodetic Vertical Datum of 1929. Initially, all data points were surveyed with reference to the 1983 State Planar Coordinate System to be compatible with the facility's mapping system. However, these data were then converted to the 1927 coordinate system to be compatible with the USAEC's IRDMIS data base. Geotrack, Inc. used the 1983

data to locate the surveyed points on the facility's electronic files. The SWMU location maps were then produced from the electronic files. Table 4.2 presents the elevations and location coordinates (northings and eastings in the 1927 system format) of the data points surveyed for this investigation.

4.8.0.2. The elevations of all eight monitoring wells installed by Parsons ES were surveyed at the top of the casing (T.O.C.) and at the concrete pad (equivalent to ground surface elevation). Location coordinates were also surveyed for the wells. Although the Work Plan called only for estimates of elevations for all soil borings, elevations of the borings for SWMUs 48 and 54 were surveyed by Geotrack. The elevations of the three staff gauges and the concrete abutment measuring point were surveyed. All other elevation and location coordinate data, including the soil borings at SWMU 17 and the background metals study soil borings, were estimated using data from the nearest surveyed point.

4.9 SAMPLING AND ANALYSIS PROGRAM

4.9.0.1. The sampling and analysis program was designed to meet the objectives stated in Subsection 1.2 of this report. The locations and numbers of samples and the analyses performed were selected to optimize the identification of sources of contaminants, pathways of contaminant migration, and the extent of contamination. The sampling methodologies considered the characteristics of known contaminants as well as the need to identify suspected contaminants. The program was carried out in accordance with the sampling procedures, analytical methodology, and sample nomenclature described in the Work Plans and Quality Assurance Project Plan (QAPP). The following subsections describe what samples were collected, what analyses were performed, and any deviations from the Work Plans or QAPP. The analytical results are discussed in detail in subsequent sections. Sample locations are shown on the location maps for the area of concern in subsequent sections. A summary of all samples collected, including QA/QC samples, and the analyses performed (with USEPA analytical method numbers) is presented in Table 4.3 for aqueous samples and Table 4.4 for solid samples.

4.9.1 Surface Water

4.9.1.1. A total of nine surface water samples were collected from the New River, a spring directly discharging to the river, and Stroubles Creek. Sample SPG3SW1 was from a

TABLE 4.2
SURVEY DATA
RADFORD ARMY AMMUNITION PLANT

SWMU	Well	Elevation of T.O.C. (1)	Coordinates (2) Northing	Easting
17	INJ1	1872.43	313343	1403827
	INJ2	1866.28	313055	1404221
31	31MW1	1715.04	319116	1397410
	31MW2	1699.05	319485	1397410
	31MW3	1698.82	319382	1397251
	31MW4	1698.55	319208	1397041
48	48MW1	1819.95	319695	1409679
	48MW2	1818.88	319446	1409717
	48MW3	1812.17	319463	1409912
	48MW4	1832.60	319840	1409453

SWMU	Staff Gauge	Elevation of 3.0' mark
31	31SG1	1692.23
	31SG2	1687.54
	31SG3	1685.10

SWMU	Soil Boring	Ground Surface Elevation
48	48SB4	1830.4
	48SB5	1823.5
54	54SB1	1697.3
	54SB2	1699.1
	54SB3	1696.6
	54SB4	1697.0
	54SB5	1697.0
	54SB6	1700.9
	54SB7	1700.1
	54SB8	1699.4
	54SB9	1697.9
	54SB10	1696.6
	54SB11	1697.3
	54SB12	1696.8
	54SB13	1700.0
	54SB14	1699.6
	54SB15	1704.5
	54SB16	1697.0

(1) For monitoring and injection wells elevations are given for the top of casing (T.O.C.). All elevations are in feet above mean sea level.

(2) Coordinates given in Virginia State Planar System, North American Datum 1927 - CONUS. Clarke, 1866.

NOTE: Only those points surveyed are shown; survey data of other points were estimated in accordance with the Work Plan.

G:\JOBS\722\722843\SURVEY.XLS

TABLE 4.3
RFI ANALYTICAL PROGRAM: AQUEOUS SAMPLES
RADFORD ARMY AMMUNITION PLANT

Area	Field Sample Name	Media(2)	Analytical Parameter (1)											Comments
			Total Metals	Diss. Metals (3)	Explosives	VOCs	SVOCs	TOC	TOX	TPH	Chloride	Hardness	COD	Field Meas. (3)	
SWMU 17															
Contaminated	17PZ1	GW	Z	X, Z	X			X	X					X, Z	
Waste	17MW2	GW	Z	X, Z	X			X	X					X, Z	
Burning Area	17MW3	GW	Z	X, Z	X			X	X					X, Z	
	40MW3	GW	Z	X, Z	X			X	X					X, Z	
SWMU 17															
Discharge Point	SPG3SW1	SW	X		X			X	X					X, Z	
SWMU 31															
Coal Ash	31MW1	GW	Z	X, Z				X	X					X, Z	
Settling Lagoons	31MW2	GW	Z	X, Z				X	X					X, Z	
	31MW3	GW	Z	X, Z				X	X					X, Z	
	31MW4	GW	Z	X, Z				X	X					X, Z	
SWMU 48															
Oily Wastewater	48MW1	GW	Z	X, Z		Z	X	X	X	X	X	X	X	X, Z	
Disposal Area	48MW2	GW	Z	X, Z		Z	X	X	X	X	X	X	X	X, Z	
	48MW3	GW	Z	X, Z		Z	X	X	X	X	X	X	X	X, Z	
	48MW4	GW	Z	Z		Z	Z							Z	
SWMU 54															
Propellant Ash															
Disposal Area	54MW1	GW	Z	Z	Z			Z	Z					Z	
	54MW2	GW	Z	Z	Z			Z	Z					Z	
	54MW3	GW	Z	Z	Z			Z	Z					Z	
Stroubles Creek	SCSW1	SW	X		X	X	X	X	X		X	X		X	
	SCSW2	SW	X		X	X	X	X	X		X	X		X	
New River	NRSW1	SW	Z		Z	Z	Z	Z	Z		Z	Z		Z	
	NRSW2	SW	Z		Z	Z	Z	Z	Z		Z	Z		Z	
	NRSW3	SW	Z		Z	Z	Z	Z	Z		Z	Z		Z	
	NRSW4	SW	Z		Z	Z	Z	Z	Z		Z	Z		Z	
	NRSW5	SW	Z		Z	Z	Z	Z	Z		Z	Z		Z	
	NRSW6	SW	Z		Z	Z	Z	Z	Z		Z	Z		Z	

TABLE 4.3 (Contined)
RFI ANALYTICAL PROGRAM: AQUEOUS SAMPLES
RADFORD ARMY AMMUNITION PLANT

Area	Field Sample Name	Media(2)	Analytical Parameter (1)											Comments
			Total Metals	Diss. Metals (3)	Explosives	VOCs	SVOCs	TOC	TOX	TPH	Chloride	Hardness	COD	Field Meas. (3)	
QA/QC Samples															
SWMU 17 Contaminated Waste Burning Area	17FBAQGW	GW	X		X			X	X						Field Blank
SWMU 17 Discharge Point	SPG3FBAQ	SW	X		X			X	X						Field Blank
SWMU 31 Coal Ash Settling Lagoons	31MW5	GW	X					X	X						Field Duplicate of 31MW3
SWMU 48 Oily Wastewater Disposal Area	48EQGW	GW	X				X	X	X	X	X	X	X		Equipment Blank
	48MWTB	GW				Z									Trip Blank
	48MWTB2	GW				Z									Trip Blank
SWMU 54 Propellant Ash Disposal Area	54MWEQ	GW	Z	Z	Z			Z	Z						Equipment Blank
New River	NRSW8	SW	Z		Z	Z	Z	Z	Z		Z	Z			Field Duplicate of NRSW5
	NRSWTB2	SW				Z									Trip Blank
	NRSWTB3	SW				Z									Trip Blank
	NRSWFB	SW	Z		Z	Z	Z	Z	Z		Z	Z			Field Blank
Stroubles Creek	SCSW3	SW	X		X	X	X	X	X		X	X			Field Duplicate of SCSW 2
	SCTBAQ	SW				X									Trip Blank

(1) ANALYTICAL PARAMETERS
Metals (Total and Dissolved) by SW-846 6010/7000 series.
Explosives by SW-846 8330
Volatile Ogranics (VOCs) by SW-846 8240
Semivolatile Ogranics (SVOCs) by SW-846 8270
Total Organic Carbon (TOC) by MCAWW 415.1
Total Petroleum Hydrocarbons (TPH) by SW-846 3550/MCAWW 418.1
Chloride
Hardness by SM2340-B
COD

(2) MEDIA
GW - Groundwater
SW - Surface Water

(3) FIELD MEASUREMENTS
pH, temperature, and conductivity, measured at the time of collection

NOTES: X indicates January 1995 sampling
Z indicates July 1995 sampling
Dissolved metals were sampled in January and July 1995

TABLE 4.4
RFI ANALYTICAL PROGRAM: SOLID SAMPLES
RADFORD ARMY AMMUNITION PLANT

Area	Field Sample Name (2)	Media (3)	Analytical Parameter (1)										
			Metals	Explosives	VOCs	SVOCs	TOC	TOX	TPH	BTU	pH	Waste Char.	Comments
SWMU 17 (17A) Stage and Burn Area	17ASB105	SO	X	X	X	X							
	17ASB110	SO	X	X									
	17ASB115	SO	X	X									
	17ASB120	SO	X	X									
	17ASB122	SO	X	X	X	X							
	17ASB1	SO					X			X		X	Composite Sample
	17ASB205	SO	X	X	X	X							
	17ASB210	SO	X	X									
	17ASB215	SO	X	X									
	17ASB220	SO	X	X									
	17ASB225	SO	X	X	X	X							
	17ASB2	SO					X			X		X	Composite Sample
	17ASS3	SO	X	X									
	17ASB305	SO	X	X	X	X							
	17ASB310	SO	X	X									
	17ASB315	SO	X	X									
	17ASB320	SO	X	X									
	17ASB325	SO	X	X	X	X							
	17ASB3	SO					X			X		X	Composite Sample
SWMU 17 (17B) ACD Staging Area	17BSS1	SO	X	X									
	17BSS2	SO	X	X									
ACD	17CSB105	SO	X	X									
	17CSB110	SO	X	X									
	17CSB114	SO	X	X									
	17CSB1	SO					X			X		X	Composite Sample
	17CSB205	SO	X	X									
	17CSB210	SO	X	X									
	17CSB215	SO	X	X									
	17CSB2	SO					X			X		X	Composite Sample

TABLE 4.4 (Continued)
RFI ANALYTICAL PROGRAM: SOLID SAMPLES
RADFORD ARMY AMMUNITION PLANT

Area	Field Sample Name (2)	Media (3)	Analytical Parameter (1)										
			Metals	Explosives	VOCs	SVOCs	TOC	TOX	TPH	BTU	pH	Waste Char.	Comments
SWMU 17													
17 (D)													
ACD Ash	17DSB105	SO	X	X									
Staging Area	17DSB110	SO	X	X									
	17DSB115	SO	X	X									
	17DSB120	SO	X	X									
	17DSB125	SO	X	X									
	17DSB127	SO	X	X									
	17DSB1	SO					X			X		X	Composite Sample
	17DSB205	SO	X	X									
	17DSB210	SO	X	X									
	17DSB215	SO	X	X									
	17DSB220	SO	X	X									
	17DSB225	SO	X	X									
	17DSB2	SO					X			X		X	Composite Sample
SWMU 17													
Discharge Point	SPG3SE1	SE	X	X			X	X					
SWMU 31	31MW1A25	SO	X										
Coal Ash	31MW1B35	SO	X										
Settling Lagoons	31MW2A12	SO	X										
	31MW2B22	SO	X										
	31MW3A10	SO	X										5-10' Interval Sampled
	31MW3B20	SO	X										15-20' Interval Sampled
	31MW4A12	SO	X										
	31MW4B22	SO	X										
	31SE1	SE					X			X		X	Composite Sample
	31SE2	SE								X		X	Composite Sample
	31SE3	SE					X			X		X	Composite Sample
	31SE4	SE								X		X	Composite Sample
	31SE5	SE					X			X		X	Composite Sample
	31SE6	SE								X		X	Composite Sample

TABLE 4.4 (Continued)
RFI ANALYTICAL PROGRAM: SOLID SAMPLES
RADFORD ARMY AMMUNITION PLANT

Area	Field Sample Name (2)	Media (3)	Analytical Parameter (1)										Comments
			Metals	Explosives	VOCs	SVOCs	TOC	TOX	TPH	BTU	pH	Waste Char.	
SWMU 48	48SB4A11	SO		X	X	X			X				10-11' Interval Sampled
Oily Wastewater	48SB4B21	SO		X	X	X	X		X				20-21' Interval Sampled
Disposal Area	48SB4	SO								X		X	Composite Sample
	48SB5A19	SO				X			X				
	48SB5B37	SO				X	X		X				
	48SB5	SO								X		X	Composite Sample
	48SS1	SO	X	X	X	X			X				
	48SS2	SO	X	X	X	X			X				
	48SS3	SO	X	X	X	X			X				
	48SS4	SO	X			X			X				
	48SS5	SO	X			X			X				
	48SS6	SO	X			X			X				
	48MW1A22	SO				X			X				
	48MW1B54	SO				X	X		X				
	48MW2A42	SO				X			X				
	48MW2B46	SO				X	X		X				
	48MW3A22	SO				X			X				
	48MW3B32	SO				X	X		X				
SWMU 54													
Propellant Ash	54SS1	WA										X	Composite Sample
Disposal Area	54SS2	WA										X	Composite Sample
	54SB1A2	SO	X	X									
	54SB1B22	SO	X	X			X						
	54SB2A2	SO	X	X									
	54SB2B17	SO	X	X									
	54SB3A2	SO	X	X									
	54SB3B17	SO	X	X									
	54SB4A2	SO	X	X									
	54SB4B17	SO	X	X									
	54SB5A2	SO	X	X									
	54SB5B17	SO	X	X									

TABLE 4.4 (Continued)
RFI ANALYTICAL PROGRAM: SOLID SAMPLES
RADFORD ARMY AMMUNITION PLANT

Area	Field Sample Name (2)	Media (3)	Analytical Parameter (1)										Comments
			Metals	Explosives	VOCs	SVOCs	TOC	TOX	TPH	BTU	pH	Waste Char.	
SWMU 54	54SB6A2	SO	X	X									
Propellant Ash	54SB6B15	SO	X	X									10-15' Interval Sampled
Disposal Area	54SB7A2	SO	X	X									
	54SB7B17	SO	X	X									
	54SB8A2	SO	X	X									
	54SB8B17	SO	X	X									
	54SB9A7	SO	X	X									
	54SB9B17	SO	X	X									
	54SB10A2	SO	X	X									
	54SB10B17	SO	X	X			X						
	54SB11A2	SO	X	X									
	54SB11B17	SO	X	X									
	54SB12A2	SO	X	X									
	54SB12B17	SO	X	X									
	54SB13A2	SO	X	X									
	54SB13B22	SO	X	X									
	54SB14A2	SO	X	X									
	54SB14B15	SO	X	X			X						11-12' Interval Sampled
	54SB15A6	SO	X	X									
	54SB16A2	SO	X	X									
	54SB16B12	SO	X	X			X						
Stroubles	SCSE1	SE	X	X	X	X	X	X					
Creek	SCSE2	SE	X	X	X	X	X	X					
New River	NRSE1	SE	X	X	X	X	X	X					
	NRSE2	SE	X	X	X	X	X	X					
	NRSE3	SE	X	X	X	X	X	X					
	NRSE4	SE	X	X	X	X	X	X					
	NRSE5	SE	X	X	X	X	X	X					
	NRSE6	SE	X	X	X	X	X	X					

TABLE 4.4 (Continued)
RFI ANALYTICAL PROGRAM: SOLID SAMPLES
RADFORD ARMY AMMUNITION PLANT

Area	Field Sample Name (2)	Media (3)	Analytical Parameter (1)										Comments
			Metals	Explosives	VOCs	SVOCs	TOC	TOX	TPH	BTU	pH	Waste Char.	
Background Soil Sampling	BG1BUC3	SO	X				X				X		
	BG1CUC8	SO	X										
	BG2BUC5	SO	X										
	BG2CUC11	SO	X										
	BG3BUC3	SO	X										
	BG3CUC22	SO	X										
	BG4BUC5	SO	X										
	BG4CUC17	SO	X				X				X		
	BG5BUC3	SO	X										
	BG5CUC8	SO	X										
	BG6BUC5	SO	X										
	BG6CUC12	SO	X										
	BG7BUC5	SO	X										
	BG7CUC22	SO	X										
	BG8BUC5	SO	X				X				X		
	BG8CUC10	SO	X				X				X		
	BG1BBL4	SO	X				X				X		
	BG1CBL10	SO	X				X				X		
	BG2BBL5	SO	X										
	BG2CBL17	SO	X				X				X		
	BG3BBL3	SO	X										
	BG3CBL22	SO	X										
	BG4BBL5	SO	X				X				X		
	BG4CBL10	SO	X										
	BG1BWL5	SO	X										
	BG1CWL8	SO	X										
	BG2BWL4	SO	X										
	BG2CWL12	SO	X										
	BG3BWL3	SO	X										
	BG3CWL22	SO	X				X				X		
	BG4BWL4	SO	X										
	BG4CWL17	SO	X										
	BG5BWL3	SO	X				X				X		
	BG5CWL8	SO	X				X				X		
	BG6BWL4	SO	X				X				X		
	BG6CWL17	SO	X										

TABLE 4.4 (Continued)
RFI ANALYTICAL PROGRAM: SOLID SAMPLES
RADFORD ARMY AMMUNITION PLANT

Area	Field Sample Name (2)	Media (3)	Analytical Parameter (1)										Comments
			Metals	Explosives	VOCs	SVOCs	TOC	TOX	TPH	BTU	pH	Waste Char.	
QA/QC Samples													
SWMU 17													
Stage and Burn	17AFBSO	SO	X	X	X	X							Field Blank
Area 17(A)	17ASB340	SO	X	X	X	X	X						Field Duplicate of 17ASB315
ACD 17(C)	17CSB240	SO	X	X			X						Field Duplicate of 17CSB210
ACD Ash 17(D) Staging Area	17DSB240	SO	X	X			X						Field Duplicate of 17DSB210
SWMU 17													
Discharge Point	SPG3FBSE	SE	X	X			X	X					Field Blank
SWMU 31													
Coal Ash Settling Lagoons	31MWFBSO	SO	X										Field Blank
	31MWEQSO	SO	X										Equipment Blank
	31MW4C40	SO	X										Field Duplicate of 31MW4A12
SWMU 48													
Oily Wastewater	48TBSO	SO			X								Trip Blank
Wastewater Disposal	48EQSO	SO	X	X	X	X	X		X				Equipment Blank
Area	48SS8	SO	X	X	X	X	X		X				Field Duplicate of 48SS2
SWMU 54													
Propellant Ash	54TBSO	SO			X								Trip Blank
Disposal Area	54EQSO1	SO	X	X			X						Equipment Blank
	54FBSO	SO	X	X			X						Field Blank
	54SB10B20	SO	X	X			X						Field Duplicate of 54SB10B17
	54SB16B25	SO	X	X			X						Field Duplicate of 54SB16B12
	54EQSO2	SO	X	X			X						Equipment Blank
	54EQSOWA	WA	X										Equipment Blank
Stroubles Creek	SCEQSE	SE	X	X	X	X	X	X					Equipment Blank
	SCSE3	SE	X	X	X	X	X	X					Field Duplicate of SCSE2
New River	NRSE8	SE	X	X	X	X	X	X					Field Duplicate of NRSE5
	NRSEEQ	SE	X	X	X	X	X	X					Equipment Blank

TABLE 4.4 (Continued)
RFI ANALYTICAL PROGRAM: SOLID SAMPLES
RADFORD ARMY AMMUNITION PLANT

Area	Field Sample Name (2)	Media (3)	Analytical Parameter (1)										Comments
			Metals	Explosives	VOCs	SVOCs	TOC	TOX	TPH	BTU	pH	Waste Char.	
Background Soil Sampling	BG4CUCD	SO	Z				Z				X		Duplicate of BG4CUC17
	BG4BBLD	SO	Z				Z				X		Duplicate of BG4BBL5
	BG5CWLD	SO	Z										Duplicate of BG5CWL8
	FBLK1	SO	Z										Field Blank
	EQBLK	SO	Z										Equipment Blank

(1) ANALYTICAL PARAMETERS

Metals by SW-846 6010/7000 series
Explosives by SW-846 8330
Volatile Organics (VOCs) by SW-846 8240
Semivolatile Organics (SVOCs) by SW-846 8270
Total Organic Carbon (TOC) by MCAWW 415.1
Total Organic Halogens (TOX) lby SW-846 9020
Total Petroleum Hydrocarbons (TPH)
by SW-846 3350/MCAWW 418.1
British Thermal Units (BTU) by ASTM D240-76
Waste Characterization (Waste Char.) Includes:
TCLP Metals by SW-846 1211/6010/7000 Series
Ignitability by SW846 7.1.2.2
Corrosivity by SW-846 9045
Reactivity by Chap 7/9030, 9012
Paint Filter Test by SW-846 9095

(2) FIELD SAMPLE NAME

The Sample Name indicates Area (SWMU or River, etc), Type (SB is a boring sample, ss is a surface soil, BG is a Background Sample), and depth (unless otherwise noted, for "SB" samples, last two digits is botton of 2 ft spoon interval, for "BG" samples, the number following the soil type is the bottom of 2 ft spoon interval).
Soil Types for "BG" SX are:
UC = Unison Urban Complex
BL = Braddock Loam
WL = Whelling Loam

(3) MEDIA

SO - Soil
SE- Sediment

Notes: The Background Soil Samples (BG and the New River Samples (NR) were collected in July 1995. All others were Sampled December 1994 or January 1995.

spring determined to be the discharge point of the dye injected at SWMU 17. It was sampled in January 1995 for metals, explosives, total organic carbon (TOC), and total organic halogens (TOX). This was the only location identified as a discharge point for SWMU 17.

4.9.1.2. Two surface water samples were collected from Stroubles Creek in January 1995. The creek, a main tributary to the New River, was sampled upstream of the facility (SCSW1) and at the point of discharge to the river (SCSW2), for metals, explosives, TOC, TOX, volatile organic compounds (VOCs), semi-volatile compounds (SVOCs), hardness, and chloride. The creek was relatively high and fast moving at the time of sampling.

4.9.1.3. Six surface water samples were collected from the New River in July 1995 for characterization purposes. The samples were analyzed for the same parameters listed in 4.9.1.2 above. The samples, which were intended to provide supplemental risk assessment information, were located near the likely discharge points of SWMU 31 (NRSW6), SWMU 48 (NRSW4), and SWMU 54 (NRSW5), or up river of the facility (NRSW1, 2, and 3).

4.9.1.4. In addition to those samples, associated surface water QA/QC samples were also collected in accordance with the QAPP. Those included a trip blank and field duplicate for the Stroubles Creek samples, a field blank for the spring sample, and a field duplicate, trip blank and field blank associated with the New River samples. Field parameters, including pH, temperature, and conductivity, were collected for all surface water samples.

4.9.2 Groundwater

4.9.2.1. A total of 15 groundwater samples were collected from the eight new monitoring wells and from several existing wells at SWMUs 17/40 and 54. Eleven wells were sampled in January 1995 and all 15 wells were sampled in July 1995 (when 48MW4 was installed and the SWMU 54 wells were added). The sampling procedures followed the Work Plan with only minor deviations as described below.

4.9.2.2. Based upon comments received from the USEPA after completion of the initial round of groundwater sampling, additional sampling was scheduled. Initially, only dissolved metals were collected from all of the wells. In July 1995, it was determined that total metals analyses were also required. Therefore, in July 1995, all of the wells were

sampled for total metals and re-sampled for dissolved metals so that the metals data from the two parameters would not be affected by the time passage between sampling events.

4.9.2.3. Purging of the wells was generally completed by hand bailing with PVC bailers for shallow wells and submersible pumps for deeper wells. All groundwater samples were collected in disposable polyethylene bailers. A pressure filter device (0.45 micron) was attached to the bailer for the collection of dissolved metals samples. Field parameters, including pH, temperature, and conductivity, were measured before and after collection of the sample. Table 4.1 includes groundwater elevations recorded in July 1995, when all wells were gauged and sampled.

4.9.2.4. Three monitoring wells at SWMU 17 were sampled for total metals, dissolved metals, explosives, TOC, and TOX. One well at SWMU 40 was sampled for the same parameters. All were bedrock wells. Shallower wells 40MW2 and 40MW4 were dry in January and July 1995 and could not be sampled. Well 17MW3, a deep bedrock well, was purged by hand bailing due to a pump malfunction; the other wells were purged with a pump. In general, all wells recharged quickly enough to remove the required volumes of groundwater, but all were completely dried once or twice before the required purge volume was achieved. Associated QA/QC samples included a field blank.

4.9.2.5. Four monitoring wells were sampled at SWMU 31 for total metals, dissolved metals, TOC, and TOX. All four wells were purged by hand bailing. Only 31MW2 and 31MW3 were purged dry before the required volume was achieved (in the July 1995 event); the others had moderate to good recharge rates. A field duplicate was taken for QA/QC purposes.

4.9.2.6. Three monitoring wells at SWMU 48 were sampled for total metals, dissolved metals, VOCs, SVOCs, TOC, TOX, total petroleum hydrocarbons (TPH), chloride, hardness, and chemical oxygen demand (COD). The well installed in July 1995 (48MW4) was sampled for total and dissolved metals, and VOCs. All four wells were completed in the bedrock. Recharge in these wells ranged from slow to very slow. 48MW4 was purged by hand bailing because of a pump malfunction; 48MW2 was purged by hand because of the small diameter of the well. 48MW1 and 48MW3 were purged by pumping. VOCs were added as an

analytical parameter (for all four wells) to the July re-sampling event; VOC samples were not collected in January 1995. QA/QC samples included an equipment blank and two trip blanks.

4.9.2.7. Sampling of the monitoring wells at SWMU 54 was not proposed in the Work Plan. However, to supplement risk assessment and site characterization information, the three monitoring wells, which were not sampled in January 1995, were included in the sampling activities during July 1995. The wells were sampled for total metals, dissolved metals, explosives, TOC, and TOX. Wells 54MW1 and 54MW2 were relatively slow rechargers; all were purged by hand bailing. An equipment blank was taken for QA/QC purposes.

4.9.3 Soil

4.9.3.0.1. Surface and subsurface soil samples were collected during the investigation for chemical analysis. In addition, soil samples (generally subsurface) were also submitted for geotechnical analysis in accordance with USAEC requirements. The sample totals discussed below include the subsurface soils taken for the soil metals background study. All samples were collected following the Work Plan procedures unless otherwise noted below.

4.9.3.1 Surface Soils

4.9.3.1.1. A total of nine surface soil samples were collected with a stainless steel bowl and spoon for the investigation. All were sampled in December 1994. Three samples, 17ASS3, 17BSS1, and 17BSS2 were taken at SWMU 17. 17ASS3 was the top layer (0-0.5 feet) of the 17ASB3 boring sample. These surface soil samples were analyzed for total metals and explosives.

4.9.3.1.2. Six surface soil samples were collected at SWMU 48. Three samples were taken from the upper disposal area and analyzed for total metals, explosives, VOCs, SVOCs, and TPH. Three samples were collected from the lower disposal area and submitted for total metals, SVOCs, and TPH analysis. All six samples were obtained with a stainless steel spoon and bowl. A field duplicate sample was taken for QA/QC purposes.

4.9.3.2 Subsurface Soils

4.9.3.2.1. A total of 126 subsurface soil samples were collected for the investigation. This total includes samples composited for remediation and disposal characterization but does not count samples submitted for geotechnical analysis. All sampling was done by split spoon methodology as described in the Work Plan. The sample name, as shown on Table 4.3 includes the depth. Unless otherwise specified, the depth is indicated by the last one or two digits of the name with the number being the bottom of the two foot spoon interval, e.g., 17ASB105 was taken from a depth of 3-5 feet. Depths were specified in the Work Plan based on a review of previous data or an assessment of site conditions. Any deviations from this plan are based on field observations or physical difficulties in obtaining the sample from the proposed depth.

4.9.3.2.2. A total of 39 subsurface soil samples from seven borings in four separate areas of SWMU 17 were collected. Five samples from boring 17ASB1 were taken at five foot intervals and analyzed for total metals and explosives. Additionally, the shallowest and deepest samples of this boring were submitted for VOCs and SVOCS. A sample composited from the entire hole was analyzed for TOC, British Thermal Units (BTUs), and waste characterization (TCLP-full list, corrosivity, ignitability, reactivity, and the paint filter test). The sample plan was the same for borings 17ASB2 and 17ASB3.

4.9.3.2.3. In a different area of SWMU 17, three subsurface soil samples were collected from boring 17CSB1 at five foot intervals for total metals and explosives analysis. A composite of the entire hole was submitted for TOC, BTU, and waste characterization analysis. The sample plan was the same for boring 17CSB2. Drilling auger refusal was encountered sooner than predicted in this area resulting in two fewer samples being collected from each boring than was proposed in the Work Plan. Auger refusal was at approximately 15 feet.

4.9.3.2.4. Boring 17DSB1 produced six samples and one composite, which were submitted for the same analyses as described in 4.9.3.2.3 above. Bedrock was not reached in this hole until drilling had progressed beyond the depth predicted in the Work Plan. Therefore, an additional sample was taken. Boring 17DSB2 produced five samples and one composite, which were submitted for the same analyses as 17DSB1. SWMU 17 subsurface soil QA/QC samples included a field blank and three field duplicates.

4.9.3.2.5. Eight total subsurface soil samples were collected from SWMU 31, two from each monitoring well boring. The samples were submitted for total metals analysis. The intention of the sampling was to determine migration potential of the metals from the lagoons to the New River. Therefore, the samples were taken from depths at or near the lagoon water levels and at or just below the lagoon bottoms. The 31MW3 boring was sampled continuously with the Moss Sampler; the samples from this boring are a composite of the five foot spoon interval (e.g., 31MW3A10 is the shallow sample composited from 5-10 feet). Associated QA/QC samples included a field blank, equipment blank, and a field duplicate.

4.9.3.2.6. Two subsurface soil samples and one composite of the hole were taken from each of two soil borings at SWMU 48. The shallowest sample from the boring (48SB4) in the upper disposal area was analyzed for explosives, VOCs, SVOCs, and TPH. The deepest sample was analyzed for those parameters plus TOC. The composite from this hole was submitted for BTU and waste characterization analysis. The samples from the boring (48SB5) in the lower disposal area were analyzed for SVOCs and TPH, with the deepest sample from the boring additionally being analyzed for TOC. The composite from this hole was analyzed for BTUs and waste characterization. Sampling depths were based on PID readings and visual observations.

4.9.3.2.7. Two subsurface soil samples were collected from each of three monitoring well borings at SWMU 48 (the 48MW4 boring soils were not sampled since this well was placed adjacent to the 48SB4 boring). The objective was to sample at the deepest level of contamination, based on PID readings and visual evidence, and just below the deepest contamination. The shallower of the two samples from each well boring was analyzed for SVOCs and TPH. The deeper of the two samples was analyzed for those parameters plus TOC. An equipment blank and a trip blank were submitted for QA/QC purposes.

4.9.3.2.8. Two subsurface soil samples from each of sixteen soil borings were proposed for SWMU 54. Due to drilling rig access problems at the north mound, only one subsurface soil sample was taken at 54SB15 (hand augered to a depth of 6 feet). Therefore the total number of samples was 31. The samples were taken from just below visual evidence of propellant ash or from 6-12 inches if no ash was visible, and from any other areas of visible contamination or just above the water table if contamination was not evident. All samples were analyzed for total metals and explosives with borings 54SB1, 54SB10, 54SB14, and

54SB16 also being analyzed for TOC. Associated QA/QC samples included a field blank, a trip blank, an equipment blank, and a field duplicate.

4.9.3.2.9. As described in Subsection 4.4, two subsurface soil samples from each of 18 soil borings advanced in three different soil types were collected for the soil background metals study. The samples were collected using continuous split spoons so that the B and C soil horizons could be identified. One soil sample from each of those horizons was taken from each boring. All samples were analyzed for total metals, Additionally, four samples from each soil type were analyzed for pH and TOC. Three field duplicates (one from each soil type), one field blank, and one equipment blank were collected for QA/QC purposes. The visual manual soil classification system was applied to the samples; a summary of this information is included in Appendix F.

4.9.3.3 Geotechnical Samples

4.9.3.3.1. A total of 31 subsurface soil samples were submitted for geotechnical analysis. The analyses included particle size distribution, Atterberg limits, and Unified Soil Classification System (USCS) categorization. Nineteen of the 31 samples were collected from the various SWMU borings with most of those coming from SWMU 54. The other 12 samples were taken during the background metals study, four from each of the three soil types. Table 4.5 presents a summary of the geotechnical sampling and analysis. The laboratory data for the geotechnical sampling is included in Appendix F.

4.9.3.3.2. All the geotechnical samples were originally intended to be collected using a Shelby tube (a thin walled sampling device). However, due to difficult drilling caused by gravel or hard conditions, little success was achieved with the Shelby tube approach; only one sample, 31MW1, could be obtained with this method. Discussions with the geotechnical laboratory project manager revealed that samples for the above listed parameters could be collected in large jars without an impact to the quality of the results. Therefore, most of the geotechnical samples were collected in two 16 ounce jars for shipment to the laboratory.

4.9.4 Sediment

4.9.4.0.1. A total of 15 sediment samples were taken from surface water bodies (Stroubles Creek and the New River) and lagoons. Surface water samples were associated with

TABLE 4.5
GEOTECHNICAL SAMPLING
RADFORD ARMY AMMUNITION PLANT

AREA	SAMPLE NAME	DEPTH
SWMU 31	31MW1	10-12'
SWMU 48	48MW2	10-12'
	48MW3	10-12'
	48SB5	10-11'
SWMU 54	54SB1	15-17'
	54SB2	10-12'
	54SB3	10-12'
	54SB4	5-7'
	54SB5	15-17'
	54SB6	15-20'
	54SB7	10-12'
	54SB8	15-17'
	54SB9	10-12'
	54SB10	10-12'
	54SB11	15-17'
	54SB12	5-7'
	54SB13	5-7'
	54SB14	7-9'
	54SB16	10-12'
BACKGROUND SOILS	BG1BUC3	3-5'
	BG4CUC17	15-17'
	BG8BUC5	3-5'
	BG8CUC10	8-10'
	BG3CWL22	20-22'
	BG5BWL3	1-3'
	BG5CWL8	6-8'
	BG6BWL4	2-4'
	BG1BBL4	2-4'
	BG1CBL10	8-10'
	BG2CBL17	15-17'
	BG4BBL5	3-5'

All samples were analyzed for particle size distribution, Atterberg limits, and Unified Soil Classification System (USCS) categorization.

the New River sediments and the Stroubles Creek sediments, but not the SWMU 31 lagoon sediments.

4.9.4.1 Surface Water Bodies

4.9.4.1.1. Two sediment samples were collected from Stroubles Creek. SCSE1 is associated with surface water sample SCSW1 (upstream of the facility) and SCSE2 is associated with SCSW2 (the discharge point of the creek into the New River). The sediments were sampled in January 1995 during relatively high, fast moving water conditions. The samples were submitted for total metals, explosives, VOCs, SVOCs, TOC, and TOX. The spring which was determined by dye tracing to be the discharge point of SWMU 17 into the New River was also sampled in January 1995. Associated with sample SPG3SW1, SPG3SE1 was sampled for total metals, explosives, TOC, and TOX. QA/QC samples included a field blank, an equipment blank, and a field duplicate.

4.9.4.1.2. Six New River sediment samples, associated with the New River surface water samples, were collected in July 1995 (see Subsection 4.9.1). The samples were taken during relatively calm, low water conditions and were analyzed for total metals, explosives, VOCs, SVOCs, TOC, and TOX. A duplicate sample and an equipment blank were collected for QA/QC purposes.

4.9.4.2 Lagoons

4.9.4.2.1. Two sediment samples were collected from each of the three lagoons at SWMU 31. The objective of the sampling was to determine the potential for eventual disposal of the sediments. The samples were analyzed for BTUs and waste characterization, with one of the two from each lagoon also being analyzed for TOC. Each sample was collected by compositing several hand augered borings from one area of the lagoon. The hand auger was advanced as deeply as possible to characterize the total sediment column. Generally, the auger could not penetrate below six feet into the sediment. This procedure was repeated in the opposite corner of the lagoon. The other lagoons were sampled in the same manner.

4.9.5 Waste

4.9.5.0.1. Two propellant ash waste samples, one from each mound, were taken at SWMU 54. The samples were submitted for waste characterization analysis (TCLP metals, corrosivity, reactivity, ignitability, and the paint filter test). The samples were collected by compositing four discrete samples from around each ash pile in a stainless steel bowl. An equipment blank was also submitted for QA/QC purposes.

4.10 INVESTIGATION DERIVED WASTE

4.10.0.1. All drilling generated fluids, well development or purge water, or general decontamination generated fluids were discharged to the facility's industrial treatment plant in accordance with the Work Plan and past investigation field practices. No fluids were discharged directly to the ground.

4.10.0.2. Soil cuttings were placed on heavy plastic sheeting and covered for protection from the elements, or were placed directly into D.O.T. type-H drums, until the results of the waste characterization sampling were known. When the analyses revealed that no hazardous constituents were present, the soil was spread around the facility. Since the soil background metals borings did not generate much soil (small diameter augers were used), and since the areas were chosen because they had never been impacted by facility activities, none of this soil was containerized.

SECTION 6

BASELINE RISK ASSESSMENT

6.1 INTRODUCTION

6.1.1 Objectives

6.1.1.1. The objectives of this baseline risk assessment are to help determine the necessity of additional response actions at RAAP; to provide a basis for determining cleanup levels that adequately protect public health and the environment; to provide a basis for comparing various remedial alternatives; and to determine if remediation is warranted (USEPA, 1989c). The focus of this assessment is the human health risk from exposure to chemicals in soil, surface water, sediments and groundwater.

6.1.1.2. Risk assessment is the technical evaluation of the nature and magnitude of potential risk; a baseline risk assessment is an analysis of the potential for adverse effects (current or future) that could be caused by hazardous substance releases from a site in the absence of any action to control or mitigate these releases. The objective of the baseline risk assessment for RAAP is to obtain information that can be used in the following decision processes:

- To document the magnitude of potential risk at a site, and to identify the primary causes of the potential risk;
- To determine whether additional response action is necessary at a particular SWMU; and
- To help support the selection of the "no-action" remedial alternative at appropriate sites.

6.1.1.3. This risk assessment was conducted in accordance with USEPA guidance including the *Risk Assessment Guidance for Superfund Human Health Evaluation Manual* (RAGS) (USEPA, 1989c), the *Supplemental Guidance to RAGS: Calculating the Concentration Term* (USEPA, 1992c), the *CERCLA Compliance with Other Laws Manual*

(USEPA, 1988) and other supporting documents. These guidance documents provide direction on evaluating the nature of chemical releases from the site, the potential pathways for human exposure, and determining the potential threat to public health and the environment as a result of such releases. A typical RCRA risk assessment normally encompasses a comparison of sampling data to health-based numbers (HBNs) or risk-based concentrations (RBCs) to determine if these concentrations pose a risk of adverse health effects through human exposure. However, RAAP is currently negotiating a Federal Facility Agreement with the USEPA. Once approved, the facility will fall under the guidance of the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) division of the USEPA. To avoid any potential future problems with remedial alternatives based upon a RCRA risk assessment, a decision was made by USAEC to follow CERCLA guidance for the assessment of human health risk.

6.1.2 Overview and General Approach

The following steps were completed sequentially for the evaluation for each SWMU:

- Identification of chemicals of potential concern;
- Exposure assessment;
- Toxicity assessment; and
- Risk characterization.

6.1.2.1. The first step of this evaluation consisted of assessing the available sampling data and determining exposure point concentrations for each medium. A preliminary conceptual site model was developed to assist in this analysis. Data collected during the Parsons ES RFI sampling events, as well as from other investigations (as appropriate), were included for evaluation as chemicals of potential concern.

6.1.2.2. The data were evaluated to determine suitability for use in the risk assessment, and were then used to calculate a representative concentration for each chemical of potential concern. The calculated concentration represents a specific medium and predicts the concentration available for intake by potentially exposed populations.

6.1.2.3. The second step is the exposure assessment, which estimates the type and magnitude of exposures to the potential chemicals of concern that are present at or migrating from a site. An exposure pathway describes how a population can be exposed to chemicals at a site. A completed exposure pathway comprises the following elements:

- A source and mechanism for chemical release;
- An environmental transport medium;
- An exposure point; and
- A human receptor and a feasible route of exposure at the exposure point.

A pathway is not complete unless each element is present.

6.1.2.4. The relationship between the toxicity of a chemical, the potential exposure to that chemical, and the potential for or severity of adverse health effects is developed in the third step. Chemicals that do not have toxicity information available are identified and evaluated qualitatively when possible. Additionally, adjustments are made to oral toxicity information to quantitatively evaluate, where possible, potential dermal exposures.

6.1.2.5. The exposure assessment and the toxicity evaluation are coupled and a quantitative representation of the nature and magnitude of risk is derived in the final step. Also, the uncertainties inherent in the data evaluation, in the exposure assumptions, in the available toxicity information, and in the risk quantitation are assessed in this step.

6.2 SELECTION OF CHEMICALS OF CONCERN

6.2.0.1. The positive results from the 1995 field investigation effort at RAAP are summarized by site (SWMU, New River or Stroubles Creek) in Tables 6.1 through 6.4. The results from these investigations are used as the basis for selecting chemicals of potential concern at the areas under investigation during this RFI. Chemicals of potential concern are chemicals identified at a site that may be hazardous to human health.

6.2.0.2. The objectives of the data evaluation and the identification of chemicals of potential concern are:

Table 6.1
Maximum Soil Concentrations[1,2]
0 - 10 Feet Sample Depth
Radford Army Ammunition Plant

CAS No.	Parameter	Max. (ppm)	Location	No. Detects	No. Samples
	Metals				
7440-38-2	Arsenic	127.72	17BSS1	28	97
7439-92-1	Lead	5256.41	17ASB105	87	97
7440-22-4	Silver	42.31	17ASB105	31	97
7440-39-3	Barium	5128.21	17ASB105	87	97
7440-41-7	Beryllium	7.39	17ASB310	81	97
7440-43-9	Cadmium	13.72	17ASB105	6	97
7440-47-3	Chromium	2051.28	17ASB105	87	97
7440-02-0	Nickel	902.56	17ASB105	87	97
7440-36-0	Antimony	77.95	17ASB105	1	97
7439-97-6	Mercury	72.13	54SB6A2	27	97
7782-49-2	Selenium	0.79	48SS4	2	97
	Semivolatiles				
117-81-7	Bis(2ethylhexyl)phthalate	10.13	17ASB105	18	55
56-55-3	Benzo(a)anthracene	0.99	17ASB105	2	55
205-99-2	Benzo(b)fluoranthene	1.92	17ASB105	1	55
191-24-2	Benzo(g,h,i)perylene	1.23	17ASB105	7	55
207-08-9	Benzo(k)fluoranthene	0.56	17ASB105	2	55
218-01-9	Chrysene	1.04	17ASB105	6	55
206-44-0	Fluoranthene	0.81	17ASB105	2	55
85-01-8	Phenanthrene	1.67	17ASB105	6	55
129-00-0	Pyrene	1.54	17ASB105	3	55
84-74-2	Di-n-butyl phthalate	12.27	48SS2	4	55
	Explosives				
121-14-2	2,4-Dinitrotoluene	25.31	54SB6A2	3	33
2691-41-0	HMX	4.68	54SB3A2	2	33
121-82-4	RDX	1.98	54SB3A2	1	33
118-96-7	2,4,6-Trinitrotoluene	2988.51	54SB3A2	8	33

1 - Analyte detection limits are listed in Table A-7 in the Quality Assurance Project Plan, Parsons ES, 1994.

2 - Soil sampling locations are listed by SWMU in the RCRA Facility Investigation Work Plan for Solid Waste, Parsons ES, 1994

Table 6.2

Maximum Groundwater Concentrations[1,2]

Radford Army Ammunition Plant

CAS No.	Parameter	Max. (ppb)	Location	No. Detects	No. Samples
	Metals				
7440-38-2	Arsenic	15.10	54MW1	1	15
7439-92-1	Lead	6.33	54MW1	1	15
7440-39-3	Barium	816.00	48MW2	12	15
7440-41-7	Beryllium	13.20	54MW1	10	15
7440-47-3	Chromium	26.60	54MW1	1	15
7440-36-0	Antimony	97.50	54MW1	1	15
	Volatiles				
71-55-6	1,1,1-Trichloroethane	4.10	48MW1	2	15
75-34-3	1,1-Dichloroethane	2.30	48MW1	1	15
75-35-4	1,1-Dichloroethylene	1.10	48MW1	1	15
56-23-5	Carbon Tetrachloride	100.00	48MW3	2	15
75-09-2	Methylene Chloride	1.10	48MW2	1	15
67-66-3	Chloroform	30.00	48MW3	2	15
127-18-4	Tetrachloroethylene	1.20	48MW1	1	15
79-01-6	Trichloroethylene	37.00	48MW3	3	15
	Semivolatiles				
117-81-7	Bis(2ethylhexyl)phthalate	23.00	48MW3	2	15
	Explosives				
2691-41-0	HMX	4.63	54MW2	2	15

1 - Analyte detection limits are listed in Table A-7 in the Quality Assurance Project Plan, Parsons ES, 1994.

2 - Soil sampling locations are listed by SWMU in the RCRA Facility Investigation Work Plan for Solid Waste, Parsons ES, 1

Table 6.3
Maximum Sediment Concentrations[1]
Radford Army Ammunition Plant

CAS No.	Parameter	Max. (ppm)	Location	No. Detects	No. Samples
	Metals				
7440-38-2	Arsenic	10.59	SCSE1	3	10
7439-92-1	Lead	4415.58	NRSE4	10	10
7440-22-4	Silver	0.21	SCSE3	10	10
7440-39-3	Barium	415.00	NRSE3	10	10
7440-41-7	Beryllium	3.03	NRSE3	7	10
7440-47-3	Chromium	77.33	NRSE3	10	10
7440-02-0	Nickel	41.83	NRSE3	10	10
7439-97-6	Mercury	0.16	NRSE4	1	10
7782-49-2	Selenium	1.85	NRSE3	1	10
	Semivolatiles				
117-81-7	Bis(2ethylhexyl)phthalate	5.10	NRSE4	1	10
56-55-3	Benzo(a)anthracene	0.72	NRSE3	4	10
84-66-2	Diethyl phthalate	6.40	NRSE4	1	10
131-11-3	Dimethyl phthalate	6.40	NRSE4	1	10
84-74-2	Di-n-butyl phthalate	10.00	NRSE$	3	10
218-01-9	Chrysene	0.90	NRSE1	5	10
206-44-0	Fluoranthene	0.80	NRSE3	6	10
85-01-8	Phenanthrene	0.82	NRSE3	6	10
129-00-0	Pyrene	1.00	NRSE3	4	10
86-30-6	N-Nitrosodiphenylamine	2.00	NRSE4	1	10
	Explosives				
118-96-7	2,4,6-Trinitrotoluene	28.89	NRSE5	1	10

1 - Analyte detection limits are listed in Table A-7 in the Quality Assurance Project Plan, Parsons ES, 1994.

Table 6.4
Maximum Surface Water Concentrations[1]
Radford Army Ammunition Plant

CAS No.	Parameter	Max. (ppb)	Location	No. Detects	No. Samples
	Metals				
7439-92-1	Lead	9.80	NRSW4	1	10
7440-39-3	Barium	48.00	SCSW3	10	10
7440-47-3	Chromium	30.90	SCSW2	1	10
	Explosives				
2691-41-0	HMX	5.30	SCSW1,2,3	3	10

1 - Analyte detection limits are listed in Table A-7 in the Quality Assurance Project Plan, Parsons ES, 1994.

- To determine the presence and levels of contamination at individual SWMUs;
- To determine whether the levels of site-related chemicals differ from background levels; and
- To determine whether the analytical data are adequate to evaluate exposure concentrations.

6.2.0.3. The analytical data were organized into a summary format appropriate for this baseline risk assessment according to the following steps:

- Gather all data available from the site investigation and sort by medium;
- Evaluate the quality of the data with respect to sample quantitation limits;
- Evaluate any tentatively identified compounds (TICs);
- Compare the potential site-related contamination with background; and
- Develop a set of data for use in the risk assessment.

6.2.1 Evaluation of Analytical Data

6.2.1.1. All available and relevant analytical data from the 1995 sampling events were collected and sorted by media. The media for which analytical data are available include: groundwater, surface water, sediments and soils. The soil analytical data were sorted into two categories: surface soils and subsurface soils. The surface soil data includes all soil samples taken from 0 to 1.5 feet below ground surface (bgs), and the subsurface soil data includes all data deeper than 1.5 feet bgs. These depth intervals were chosen to account for shallow depths that may expose site workers and deeper areas likely only to directly expose construction workers. The 0 to 1.5 foot depth interval was also chosen because a large number of soil samples collected were in this depth range, and it was determined that this would be representative of surface soils at RAAP.

6.2.1.2. The data were evaluated to determine if quality and certainty of analysis are similar between sampling periods. Under RAGS guidance (USEPA 1989c), all compatible data are used for risk assessment purposes. Groundwater data for metals from the January 1995 sampling event were replaced with the July 1995 data since only dissolved metals were analyzed in January. The exception to this selection was if a dissolved metals concentration detected during the January, 1995 sampling event was not detected during the July 1995 sampling event. Therefore, unless a significant concentration of a compound was found in a

January dissolved metals sample, only groundwater data for metals from the July 1995 sampling event were retained for analysis.

6.2.1.3. Certain analytes were not detected in every sample collected and analyzed at RAAP. The data set contains some samples with positive results and others with non-detected results. Chemicals that have not been detected in any samples of a particular medium at a SWMU were eliminated from evaluation.

6.2.2 Comparison to Background

6.2.2.0.1. As described in Subsection 4.4 of this report, Parsons ES conducted a soil background metals study as part of the RFI sampling at RAAP. This study was conducted to determine the potential presence and extent of inorganic chemical contamination at RAAP. SWMU soil metals samples were characterized and compared to background soil metals concentrations using statistical analyses to determine whether SWMU data were significantly greater than background. A previous surface soil background study was conducted at RAAP (Dames & Moore, 1992a). However, data from this study are not used in the statistical analysis presented below because of the USEPA identified deficiencies in the soil types sampled and the validity of making comparisons with samples taken at depth (SCS 1985a; 1985b). Therefore, the Dames & Moore derived soil background levels will only be used for qualitative comparisons to SWMU surface soil samples.

6.2.2.0.2. For each subset of data described below, background distributions were characterized for each metal, a tolerance limit was constructed for that metal from the background distribution, and the SWMU samples were individually compared to the tolerance limit. These calculations and data tables are presented in Appendix H. If any individual SWMU sample exceeded the calculated tolerance limit for a metal, then that SWMU was considered contaminated by that metal. Because many soil metals concentrations follow lognormal distributions, all distribution-dependent, parametric analyses (such as the Shapiro Wilk test for normality and the normal tolerance limit) are conducted using lognormally-transformed data unless otherwise noted. All summary results, however, are presented as untransformed data. The testing methodology and the results are summarized below.

6.2.2.1 Methodology

6.2.2.1.2. The first step in the analytical process was to characterize the SWMU soil metals and background data. The soil samples collected during this sampling event were from three soil types (Unison-Urban Land Complex, Wheeling Loam, and Braddock Loam) and from two soil horizons (B and C; see Subsection 3.4 of this document for a discussion of the physical characteristics of these soils and Subsection 4.4 for a description of sampling procedures); therefore, the statistical analyses were tailored to these soil types/horizons. In addition, the four sampling locations at SWMU 17 (17A, 17B, 17C, and 17D) were grouped for analysis. In this grouping, sampling area 17A was considered separately from sampling areas 17B, 17C, and 17D, which were considered as one group for the purposes of this analysis. These determinations were based on usage history and the relative proximity and similarity of 17B, 17C, and 17D, and their relative distance from 17A. All background and SWMU sample data were first grouped by soil type and soil horizon, creating 10 subsets of SWMU data and 6 subsets of background data (See Table 6.5). Each subset of SWMU data was then analyzed against the appropriate subset of background data, ensuring that each SWMU sample was compared to a background distribution from a similar soil type and soil horizon.

6.2.2.1.3. A total of 36 background soil samples were collected from unimpacted areas of the facility as described in the Revised Addendum to the Final Work Plan, Parsons ES, July 1995. The background soil plan was designed to cover the range of soil types, horizons, and depths sampled during the current and previous investigations. The background samples were, by definition, separate from the SWMU area samples. Table 6.5 summarizes the background samples collected and their applicability to a given SWMU. All background and SWMU sample data were grouped by soil type and soil horizon, creating 10 subsets of SWMU data and 6 subsets of background data. Each subset of SWMU data was then analyzed against the appropriate subset of background data, (i.e, background Braddock Loam Horizon "C" was compared to SWMU soil samples taken from Horizon "C" of the Braddock Loam), ensuring that each SWMU sample was compared to a background distribution from a similar soil type and soil horizon.

6.2.2.1.4. The background distribution of each metal was characterized for each soil type for each soil horizon. Preliminary tests were used to determine whether the background samples were normally distributed, and thus which method of calculating the tolerance limit was appropriate. If the assumptions of normality were met, then the SWMU data were compared to the background

TABLE 6.5
BACKGROUND SOIL SAMPLES
RADFORD ARMY AMMUNITION PLANT

Area	Field Sample Name	Soil Type	Applicable to SWMU No.
Background Soil Samples	BG1BUC3 BG1CUC8 BG2BUC5 BG2CUC11 BG3BUC3 BG3CUC22 BG4BUC5 BG4CUC17 BG5BUC3 BG5CUC8 BG6BUC5 BG6CUC12 BG7BUC5 BG7CUC22 BG8BUC5 BG8CUC10	UNISON-URBAN LAND COMPLEX	17*, 6, 10, 35, 41 46, 71, O, F, P
	BG1BBL4 BG1CBL10 BG2BBL5 BG2CBL17 BG3BBL3 BG3CBL22 BG4BBL5 BG4CBL10	BRADDOCK LOAM	48*, 58, 59, 68, 69
	BG1BWL5 BG1CWL8 BG2BWL4 BG2CWL12 BG3BWL3 BG3CWL22 BG4BWL4 BG4CWL17 BG5BWL3 BG5CWL8 BG6BWL4 BG6CWL17	WHEELING SANDY LOAM	31*, 54*, 13, 39

* SWMU is subject of this report.

Notes: Field sample name includes soil type, horizon, and depth, e.g., BG1BUC3 is background no. 1, "B" horizon, Unison-Urban Complex, 1-3 feet below ground surface.

distribution using the normal tolerance limit. If the assumptions of normality were not met for background, then the SWMU data were compared to background using a Poisson-based tolerance limit.

6.2.2.1.5. The first normality screen was the percentage of nondetects in the background distribution. Following EPA guidance (USEPA 1989b, USEPA 1992b, and telephone conversations with J. Brown, EPA Headquarters), if the background distribution had >50% nondetect (ND) values, then it was assumed to be nonnormal and SWMU data comparisons were conducted using the Poisson-based tolerance limits. For distributions where $0 \leq ND\% \leq 15$, all nondetect values were replaced with half of their sample quantitation limits and the distributions were tested for normality using the Shapiro Wilk normality test. If this test indicated that the background data were normally distributed, then comparisons were conducted using normal tolerance limits.

6.2.2.1.6. If the percentage of nondetects was $15 \leq ND\% \leq 50$, then the normality of the background data was tested using the Shapiro Wilk test of normality on only detected values. If the Shapiro Wilk test determined that the distribution of the detected values was non-normal, then the comparisons were conducted using Poisson-based tolerance limits as discussed above. However, if the Shapiro Wilk test determined that the distribution of the detected values was normal, then the mean and standard deviation of the distribution were adjusted using either Cohen's adjustment or Aitchison's adjustment. The appropriateness of these adjustments was determined using censored vs. detects-only probability plots, and determining which plot was most linear (See USEPA 1992b for a discussion of these methodologies). In only two cases was the percentage of nondetects for a metal between 15 and 50% (arsenic for soil horizons B and C for the Urban Complex soil type), and, in these cases, neither the detects-only nor the censored probability plot appeared linear. Therefore, the data were analyzed using Poisson-based tolerance limits.

6.2.2.1.7. Upper tolerance limits were then calculated for each background metal distribution using either the normal upper tolerance limit formula or the Poisson-based tolerance limit formula according to the criteria discussed above (See USEPA 1989b and USEPA 1992b). The limits calculated were 95% upper tolerance limits at the 95% confidence level. Analysis at this level indicates a 95% confidence level that 95% of the values of the background distribution would lie below the tolerance limit. SWMU metals values falling above these limits are considered to be significantly different from background, and thus are considered in the risk assessment.

6.2.2.1.8. Following EPA guidance, (USEPA 1989b and USEPA 1992b) the tolerance limit tests for each metal are applied by comparing each SWMU sampling point against the upper

tolerance limit calculated for that soil type and soil horizon. If any one of the SWMU sampling values lies above the upper tolerance limit, then this value is considered in the risk assessment.

6.2.2.2 Results

6.2.2.2.1. The results are summarized in Tables 6.6 through 6.12. The following results are subdivided by SWMU, and then by soil horizon. Sample locations are shown by SWMU in the Final RCRA Facility Investigation Work Plan (Parsons ES, 1994).

6.2.2.2.2. **SWMU 17A**: Three samples were taken in soil horizon B at SWMU 17A. Comparison to Unison-Urban Land Complex data indicated that SWMU samples exceeded background for antimony, arsenic, barium, cadmium, chromium, lead, nickel, and silver. 17ASB1 contributed the highest metals concentrations for each of the metals which exceeded background. Thirteen samples were taken in soil horizon C at SWMU 17A. The only exceedances of background in soil horizon C were arsenic, lead, and silver, possibly due to the fact that the soil contamination characterized by 17ASB1 was localized in soil horizon B.

6.2.2.2.3. **SWMUs 17B,C,D**: Four samples were taken in soil horizon B at SWMU 17B,C,D. The only exceedance of background was 1 of 4 samples exceeding for arsenic. Fifteen samples were taken in soil horizon C at this SWMU. Cadmium and lead exceeded background in 1 of the 15 samples (17CSB210) this soil horizon. Although one surface soil sample was collected at SWMU 17A and two surface soil samples were collected at SWMU 17B, appropriate background samples are not available for statistically rigorous comparisons. However, existing background surface soil data (Dames & Moore, 1992a) are used for qualitative comparisons in Subsection 7.5 of this report.

6.2.2.2.4. **SWMU 31**: No soil samples were taken in soil horizon B. Nine samples were taken in soil horizon C. No samples exceeded background for any metal.

6.2.2.2.5. **SWMU 48**: Samples collected in soil horizons B and C were not analyzed for metals. Although several surface soil samples were collected, appropriate background samples were not available for statistically rigorous comparison. However, background surface soil samples (Dames & Moore, 1992a) are used for qualitiative comparisons in Subsection 9.5 of this report.

6.2.2.2.6. **SWMU 54**: Fourteen samples were taken in soil horizon B at SWMU 54. Comparison to Wheeling Loam background data indicated that lead and mercury exceed background in this soil horizon. Nineteen samples were taken in soil horizon C at SWMU 54, and only one lead sample exceeded background.

6.2.2.1 Methodology

6.2.2.1.2. The first step in the analytical process was to characterize the SWMU soil metals and background data. The soil samples collected during this sampling event were from three soil types (Unison-Urban Land Complex, Wheeling Loam, and Braddock Loam) and from two soil horizons (B and C; see Subsection 3.4 of this document for a discussion of the physical characteristics of these soils and Subsection 4.4 for a description of sampling procedures); therefore, the statistical analyses were tailored to these soil types/horizons. In addition, the four sampling locations at SWMU 17 (17A, 17B, 17C, and 17D) were grouped for analysis. In this grouping, sampling area 17A was considered separately from sampling areas 17B, 17C, and 17D, which were considered as one group for the purposes of this analysis. These determinations were based on usage history and the relative proximity and similarity of 17B, 17C, and 17D, and their relative distance from 17A. All background and SWMU sample data were first grouped by soil type and soil horizon, creating 10 subsets of SWMU data and 6 subsets of background data (See Table 6.5). Each subset of SWMU data was then analyzed against the appropriate subset of background data, ensuring that each SWMU sample was compared to a background distribution from a similar soil type and soil horizon.

6.2.2.1.3. The background distribution of each metal was characterized for each soil type for each soil horizon. Preliminary tests were used to determine whether the background samples were normally distributed, and thus which method of calculating the tolerance limit was appropriate. If the assumptions of normality were met, then the SWMU data were compared to the background distribution using the normal tolerance limit. If the assumptions of normality were not met for background, then the SWMU data were compared to background using a Poisson-based tolerance limit.

6.2.2.1.4. The first normality screen was the percentage of nondetects in the background distribution. Following EPA guidance (USEPA 1989b, USEPA 1992b, and telephone conversations with J. Brown, EPA Headquarters), if the background distribution had >50% nondetect (ND) values, then it was assumed to be nonnormal and SWMU data comparisons were conducted using the Poisson-based tolerance limits. For distributions where $0 \leq ND\% \leq 15$, all nondetect values were replaced with half of their sample quantitation limits and the distributions were tested for normality using the Shapiro Wilk normality test. If this test indicated that the background data were normally distributed, then comparisons were conducted using normal tolerance limits.

TABLE 6.5
Background Sample Matrix
Radford Army Ammunition Plant

Soil Type	Soil Horizon	SWMU To Be Compared	# Background Samples	# SWMU Samples
Braddock Loam	B	48	4	0
Braddock Loam	C	48	4	0
Unison-Urban Land Complex	B	17A	8	3
Unison-Urban Land Complex	B	17BCD	8	13
Unison-Urban Land Complex	C	17A	8	4
Unison-Urban Land Complex	C	17BCD	8	15
Wheeling Sandy Loam	B	31	6	0
Wheeling Sandy Loam	C	31	6	9
Wheeling Sandy Loam	B	54	6	14
Wheeling Sandy Loam	C	54	6	19

6.2.2.1.5. If the percentage of nondetects was $15 \leq ND\% \leq 50$, then the normality of the background data was tested using the Shapiro Wilk test of normality on only detected values. If the Shapiro Wilk test determined that the distribution of the detected values was non-normal, then the comparisons were conducted using Poisson-based tolerance limits as discussed above. However, if the Shapiro Wilk test determined that the distribution of the detected values was normal, then the mean and standard deviation of the distribution were adjusted using either Cohen's adjustment or Aitchison's adjustment. The appropriateness of these adjustments was determined using censored vs. detects-only probability plots, and determining which plot was most linear (See USEPA 1992b for a discussion of these methodologies). In only two cases was the percentage of nondetects for a metal between 15 and 50% (arsenic for soil horizons B and C for the Urban Complex soil type), and, in these cases, neither the detects-only nor the censored probability plot appeared linear. Therefore, the data were analyzed using Poisson-based tolerance limits.

6.2.2.1.6. Upper tolerance limits were then calculated for each background metal distribution using either the normal upper tolerance limit formula or the Poisson-based tolerance limit formula according to the criteria discussed above (See USEPA 1989b and USEPA 1992b). The limits calculated were 95% upper tolerance limits at the 95% confidence level. Analysis at this level indicates a 95% confidence level that 95% of the values of the background distribution would lie below the tolerance limit. SWMU metals values falling above these limits are considered to be significantly different from background, and thus are considered in the risk assessment.

6.2.2.1.7. Following EPA guidance, (USEPA 1989b and USEPA 1992b) the tolerance limit tests for each metal are applied by comparing each SWMU sampling point against the upper tolerance limit calculated for that soil type and soil horizon. If any one of the SWMU sampling values lies above the upper tolerance limit, then this value is considered in the risk assessment.

6.2.2.2 Results

6.2.2.2.1. The results are summarized in Tables 6.6 through 6.12. The following results are subdivided by SWMU, and then by soil horizon. Sample locations are shown by SWMU in the Final RCRA Facility Investigation Work Plan (Parsons ES, 1994).

6.2.2.2.2. **SWMU 17A**: Three samples were taken in soil horizon B at SWMU 17A. Comparison to Unison-Urban Land Complex data indicated that SWMU samples exceeded background for antimony, arsenic, barium, cadmium, chromium, lead, nickel, and silver. 17ASB1 contributed the highest metals concentrations for each of the metals which exceeded background. Thirteen samples were taken in soil horizon C at SWMU 17A. The only exceedances of background in soil horizon C were arsenic, lead, and silver, possibly due to the fact that the soil contamination characterized by 17ASB1 was localized in soil horizon B.

6.2.2.2.3. **SWMUs 17B,C,D**: Four samples were taken in soil horizon B at SWMU 17B,C,D. The only exceedance of background was 1 of 4 samples exceeding for arsenic. Fifteen samples were taken in soil horizon C at this SWMU. Cadmium and lead exceeded background in 1 of the 15 samples (17CSB210) this soil horizon. Although one surface soil sample was collected at SWMU 17A and two surface soil samples were collected at SWMU 17B, appropriate background samples are not available for statistically rigorous comparisons. However, existing background surface soil data (Dames & Moore, 1992a) are used for qualitative comparisons in Subsection 7.5 of this report.

6.2.2.2.4. **SWMU 31**: No soil samples were taken in soil horizon B. Nine samples were taken in soil horizon C. No samples exceeded background for any metal.

6.2.2.2.5. **SWMU 48**: Samples collected in soil horizons B and C were not analyzed for metals. Although several surface soil samples were collected, appropriate background samples were not available for statistically rigorous comparison. However, background surface soil samples (Dames & Moore, 1992a) are used for qualitiative comparisons in Subsection 9.5 of this report.

6.2.2.2.6. **SWMU 54**: Fourteen samples were taken in soil horizon B at SWMU 54. Comparison to Wheeling Loam background data indicated that lead and mercury exceed background in this soil horizon. Nineteen samples were taken in soil horizon C at SWMU 54, and only one lead sample exceeded background.

TABLE 6.6
SWMU 17A, Soil Horizon B
Samples Exceeding Background
Radford Army Ammunition Plant

Field Sample Number	17ASB105	17ASB205	17ASB305	Limit	Limit Exceeded?
METALS (ug/g)					
Antimony	77.95			21	Yes
Arsenic	94.87	7.33	6.70	5.5	Yes
Barium	5128.21	64.38	71.26	601.82	Yes
Beryllium	1.65	2.23	3.40	4.5	No
Cadmium	13.72			3.5	Yes
Chromium	2051.28	46.82	53.71	340.34	Yes
Lead	5256.41	26.28	27.08	190.56	Yes
Mercury	0.29	0.18	0.18	1.5	No
Nickel	902.56	26.15	34.64	145.47	Yes
Selenium				2.5	No
Silver	42.31			1.5	Yes
Thallium				33.5	No

TABLE 6.7
SWMU 17A, Soil Horizon C
Samples Exceeding Background
Radford Army Ammunition Plant

Field Sample Number	17ASB110	17ASB115	17ASB120	17ASB122	17ASB210	17ASB215	17ASB220	17ASB225
METALS (ug/g)								
Antimony								
Arsenic	9.30	13.50	16.69			8.98		
Barium	63.12	69.20	69.36	71.50	75.69	86.91	134.26	9.56
Beryllium	2.22	2.11	1.77	2.13	2.06	4.52	6.82	
Cadmium								
Chromium	55.51	54.72	54.92	68.50	49.70	86.04	122.27	7.56
Lead	101.39	56.44	273.97	11.79	14.13	69.06	41.78	77.36
Mercury	0.14	0.16	0.11	0.09		0.12		
Nickel	24.84	29.20	24.28	28.37	27.78	56.83	78.96	6.12
Selenium								
Silver	0.39		2.12					
Thallium								

TABLE 6.7 (Continued)
SWMU 17A, Soil Horizon C
Samples Exceeding Background
Radford Army Ammunition Plant

Field Sample Number	17ASB310	17ASB315	17ASB320	17ASB325	17ASB340	Limit	Limit Exceeded?
METALS (ug/g)							
Antimony						21.5	No
Arsenic	7.51	4.64	3.75		3.30	11.5	Yes
Barium	126.39	45.16	52.97	54.71	34.58	678.55	No
Beryllium	7.39	2.20	0.57	0.77	1.55	15.03	No
Cadmium						3.5	No
Chromium	79.33	75.99	17.25	22.59	45.44	343.76	No
Lead	23.02	21.83	30.77	9.23	15.70	112.16	Yes
Mercury	0.13					1.5	No
Nickel	71.26	36.43	6.30	10.90	23.71	190.56	No
Selenium						2.5	No
Silver						1.5	Yes
Thallium						33.5	No

TABLE 6.8
SWMU 17BCD, Soil Horizon B
Samples Exceeding Background
Radford Army Ammunition Plant

Field Sample Number	17CSB105	17CSB205	17DSB105	17DSB205	Limit	Limit Exceeded?
METALS (ug/g)						
Antimony					21	No
Arsenic	11.98				5.5	Yes
Barium	29.40	36.74	68.93	65.89	601.82	No
Beryllium	3.23	1.56	1.83	1.42	4.5	No
Cadmium					3.5	No
Chromium	61.87	33.62	29.92	31.28	340.34	No
Lead	41.82	12.20	20.08	20.81	190.56	No
Mercury					1.5	No
Nickel	25.95	18.68	14.58	11.18	145.47	No
Selenium					2.5	No
Silver			0.03		1.5	No
Thallium					33.5	No

TABLE 6.9
SWMU 17BCD, Soil Horizon C
Samples Exceeding Background
Radford Army Ammunition Plant

Field Sample Number	17CSB110	17CSB114	17CSB210	17CSB215	17CSB240	17DSB110	17DSB115	17DSB120	17DSB125
METALS (ug/g)									
Antimony									
Arsenic				4.59					
Barium	78.55	84.33	70.12	104.70	86.49	60.40	67.05	69.69	72.73
Beryllium	5.19	3.61	5.77	2.52	6.21	2.02	3.21	3.04	4.77
Cadmium				4.73					
Chromium	72.81	59.89	54.29	71.92	74.38	43.94	67.82	56.07	86.92
Lead	18.44	18.73	13.68	190.60	17.24	17.95	26.54	12.36	28.23
Mercury	0.10								
Nickel	46.17	35.33	46.60	45.62	56.83	16.21	28.97	45.53	50.40
Selenium									
Silver				0.04					
Thallium									

TABLE 6.9 (Continued)
SWMU 17BCD, Soil Horizon C
Samples Exceeding Background
Radford Army Ammunition Plant

Field Sample Number	17DSB127	17DSB210	17DSB215	17DSB220	17DSB225	17DSB240	Limit	Limit Exceeded?
METALS (ug/g)								
Antimony							21.5	No
Arsenic		6.32	11.32			8.03	11.5	No
Barium	111.48	80.98	142.65	111.91	55.95	68.85	678.55	No
Beryllium	5.89	2.48	7.88	5.48	11.84	2.23	15.03	No
Cadmium							3.5	Yes
Chromium	77.87	56.30	97.09	63.30	77.76	49.18	343.76	No
Lead	23.46	17.87	23.10	11.31	8.43	14.63	112.16	Yes
Mercury	0.15		0.24				1.5	No
Nickel	66.39	28.79	72.05	57.42	87.82	23.33	190.56	No
Selenium							2.5	No
Silver	0.07						1.5	No
Thallium							33.5	No

TABLE 6.10
SWMU 31, Soil Horizon C
Samples Exceeding Background
Radford Army Ammunition Plant

Field Sample Number	31MW1A25	31MW1B35	31MW2A	31MW2B	31MW3A10	31MW3B20	31MW4A12	31MW4B22	31MW4C40	Limit	Limit Exceeded?
METALS (ug/g)											
Antimony										20.5	No
Arsenic				4.40						7	No
Barium	28.11	58.39	134.90	97.33	134.00	75.10	136.78	82.68	140.53	817.66	No
Beryllium	0.94	1.18	1.00	1.06	0.95	0.75	1.18	0.83	1.22	7.98	No
Cadmium										3.5	No
Chromium	18.50	24.10	43.94	34.00	26.80	19.50	43.91	32.03	44.13	306.88	No
Lead	0.63	7.32	21.16	20.86	31.54	40.00	17.70	13.96	19.98	140.67	No
Mercury				0.07	0.18					2	No
Nickel	23.62	30.89	13.37	22.78	12.60	13.30	20.23	18.18	21.49	129.86	No
Selenium										2.5	No
Silver		0.02				0.11				1.5	No
Thallium										31.5	No

TABLE 6.11
SWMU 54, Soil Horizon B
Samples Exceeding Background
Radford Army Ammunition Plant

Field Sample Number	54SB10A	54SB11A	54SB12A	54SB13A	54SB14A	54SB16A	54SB1A	54SB2A	54SB3A	54SB4A	54SB5A	54SB6A	54SB7A	54SB8A	Limit	Limit Exceeded?
METALS (ug/g)																
Antimony															20.5	No
Arsenic	4.28							3.27				4.08			6.5	No
Barium	319.23	223.57	235.96	226.99	153.30	231.33	164.51	224.22	178.16	313.51	281.80	1077.02	138.29	188.63	1244.45	No
Beryllium	1.81	1.49	1.54	1.42	0.89	1.47	0.93	1.76	1.11	1.78	1.55	1.11	0.82	1.15	5	No
Cadmium							2.40					11.75			3.5	No
Chromium	33.86	33.17	36.08	31.29	20.52	34.27	25.38	27.91	28.16	35.56	34.54	136.92	24.00	27.69	378.59	No
Lead	205.56	91.13	21.22	134.97	36.56	31.82	716.80	2354.26	321.84	84.26	39.90	3789.73	50.29	229.75	161.81	Yes
Mercury							0.09	0.13	5.06			72.13			1.5	Yes
Nickel	19.71	20.05	20.10	18.90	12.38	20.56	11.66	10.25	13.45	21.44	21.20	16.99	12.34	15.60	173.55	No
Selenium															2.5	No
Silver	0.07			0.07			0.07	0.03	0.03	0.04	0.04	0.30			2	No
Thallium															32	No

TABLE 6.12
SWMU 54, Soil Horizon C
Samples Exceeding Background
Radford Army Ammunition Plant

Field Sample Number	54SB10B	54SB10D	54SB11B	54SB12B	54SB13B	54SB14B	54SB15A	54SB16B	54SB16D	54SB1B	54SB2B	54SB3B	54SB4B	54SB5B
METALS (ug/g)														
Antimony														
Arsenic														
Barium	158.09	141.88	175.55	248.34	118.64	166.27	338.27	203.70	237.56	307.44	175.46	87.63	108.30	244.59
Beryllium	1.20	1.03	1.34	1.82		1.08	1.93	1.48	1.77		1.33			1.61
Cadmium														
Chromium	29.78	27.23	32.93	46.48	32.32	34.10	45.93	34.20	43.53	9.80	29.45	37.76	21.30	40.64
Lead	11.69	13.16	12.11	13.28	8.23	13.25	28.40	14.81	13.68	5.77	14.23	14.74	8.36	16.82
Mercury	0.12											0.21		
Nickel	18.01	15.45	18.89	26.43	13.20	20.12	26.05	20.12	24.25	6.23	16.69	10.26	9.19	24.46
Selenium														
Silver	0.03	0.03									0.03	0.04	0.03	0.05
Thallium														

TABLE 6.12 (Continued)
SWMU 54, Soil Horizon C
Samples Exceeding Background
Radford Army Ammunition Plant

Field Sample Number	54SB6B	54SB7B	54SB8B	54SB9A	54SB9B	Limit	Limit Exceeded?
METALS (ug/g)							
Antimony						20.5	No
Arsenic						7	No
Barium	362.50	420.91	243.14	193.90	201.01	817.66	No
Beryllium	2.43	2.47	1.72	1.39	1.53	7.98	No
Cadmium						3.5	No
Chromium	70.14	57.10	40.15	27.93	37.56	306.88	No
Lead	430.56	22.79	21.20	20.85	15.83	140.67	Yes
Mercury						2	No
Nickel	30.14	34.72	25.56	17.68	22.61	129.86	No
Selenium						2.5	No
Silver					0.04	1.5	No
Thallium						31.5	No

6.2.3 Summary of Chemicals of Potential Concern

6.2.3.1. The chemicals of potential concern for each media at each site was compiled as a result of the tasks outlined in Section 6.2. This list included chemicals that meet the following criteria:

- Chemical was positively identified in at least 1 sample collected from the specific medium at the SWMU;
- Inorganic chemicals were detected at a concentration greater than the established background level for the specific medium;
- Chemical is a target analyte that is reported with an acceptable level of certainty associated with the chemical identification.

6.2.3.2. Thirty seven chemicals were evaluated in this risk assessment in soils, groundwater, surface water and sediment. The types of chemicals are as follows: 9 volatiles, 13 semi-volatiles, 11 metals and 4 explosives.

6.3 COMPLIANCE WITH ENVIRONMENTAL STANDARDS

6.3.1 Chemical-Specific ARARs and TBC Criteria

6.3.1.0.1. The primary guidance for identifying and evaluating the requirements of environmental statutes for Superfund sites is the *CERCLA Compliance with Other Laws Manual* (USEPA, 1988). This guidance is intended to assist in the selection of on-site remedial actions that meet the applicable, or relevant and appropriate requirements (ARARs) of the Resource Conservation and Recovery Act (RCRA), the Safe Drinking Water Act (SDWA), the Clean Air Act (CAA), the Clean Water Act (CWA), and other Federal and State environmental laws as required by CERCLA Section 121.

6.3.1.0.2. According to the manual, a requirement under other environmental laws may be either applicable or relevant and appropriate. Cleanup standards, standards of control and other substantive environmental protection requirements are considered applicable. These standards specifically address a hazardous substance, pollutant, contaminant, remedial action, location or other circumstance at a CERCLA site. Relevant and appropriate requirements are

not directly "applicable" to a specific hazardous substance at a CERCLA site, but address significantly similar situations and merit consideration.

6.3.1.0.3. ARARs can be classified as ambient or chemical-specific requirements, performance, design or other action-specific requirements, or location-specific requirements. Chemical-specific requirements are numerical values or methodologies which result in the establishment of numerical values that represent an acceptable concentration of chemical that may be discharged to the environment. Action-specific requirements are generally technology- or activity-based requirements on remedial actions at CERCLA sites. Location-specific requirements are restrictions placed on the concentration of hazardous substances or the conduct of activities due to the criticality of a type of habitat. For the purposes of this risk assessment, chemical-specific requirements will be analyzed.

6.3.1.0.4. A second level of "to-be-considered" criteria (TBCs) includes federal and state environmental criteria, advisories, guidance and proposed standards. TBCs are not legally binding and do not have the status of potential ARARs; however, appropriate TBCs may be considered as part of the site risk assessment and may be useful in determining the cleanup level for the protection of the environment and human health.

6.3.1.0.5. ARARs and TBCs identified for these SWMUs are discussed for human receptors with respect to the different media below. Table 6.13 lists appropriate ARARs evaluated for this risk assessment.

Table 6.13

Water Quality Criteria (mg/L)

Analyte	FWQC - Acute	FWQC - Chronic	VAWQC - Public
Lead	83	3.2	0.015
Barium	1	N/A	2
Chromium	1,700	210	0.17
HMX	0.4	N/A	N/A

FWQC - Federal Water Quality Criteria
VAWQC - Virginia Water Quality Criteria

6.3.1.1 Groundwater

6.3.1.1.1. Groundwater conditions at RAAP are complex in terms of defining the water table and the availability of groundwater. In general, in the lower areas of alluvial deposition located along the New River, the water table approximates the depth of the river. In the higher elevation areas, where the groundwater resides in bedrock, the water table is extremely variable. Because of the presence of karst features like solution cavities and collapse structures, and areas that are severely fractured, there is a significant potential for variable movement of groundwater through these features. Groundwater occurrence and movement is discussed in detail in Subsection 3.7 and in the SWMU-specific sections (7 through 10).

6.3.1.1.2. Groundwater at RAAP is not currently used as a public water supply serving 25 or more people. According to this criteria, MCLs (Maximum Contaminant Levels) and MCLGs (Maximum Contaminant Level Goals) for drinking water, which are promulgated under the Safe Drinking Water Act would not be appropriate as ARARs for this investigation (USEPA, 1988a).

6.3.1.2 Surface Water and Sediments

6.3.1.2.1. The New River is the main surface water feature at RAAP, with approximately 13 miles of shoreline within the boundaries of the installation. RAAP discharges approximately 25 million gallons per day (mgd) into the New River from 15

locations along the New River and Stroubles Creek (Parsons ES, 1994a). Effluent from RAAP consists of various treated process waters, wash waters, cooling waters, stormwater runoff and sanitary wastewater. Stroubles Creek, the largest tributary of the New River, originates in the southeast sector of RAAP and consists primarily of stormwater runoff and effluent from the Blacksburg, Virginia Municipal Wastewater Treatment Plant. In addition, groundwater discharging from the karst bedrock may contribute significantly to the stream flow. The wastewater effluent consists primarily of domestic and industrial wastewaters.

6.3.1.2.2. Under the authority of the Clean Water Act, the USEPA has developed Federal Water Quality Criteria (FWQC). These numerical ambient criteria are provided to protect marine and freshwater animals from chronic (long term) and acute (short term) toxicities. Since FWQCs are non-enforceable guidelines, they are considered TBCs for cleanup goals. States are required under section 303 of the Clean Water Act to adopt water quality standards based on use classifications. The state WQCs establish a maximum allowed concentration for various parameters which typically parallel the acute and chronic concentration levels of the FWQCs and are used as standards for aquatic receptors. These minimum standards are considered state ARARs. Since the New River has been classified by Virginia as suitable for use as a public water supply and the SWMUs under investigation have the potential to influence the quality of the water used for this purpose, Federal and State WQCs will be considered in this risk assessment (See Table 6.13).

6.3.1.3 Soils

6.3.1.3.1. Soil ARARs are generally applied to terrestrial flora and wildlife. There are no established Federal or Commonwealth of Virginia standards relating chemical concentrations in surface soils to toxic effects on vegetation or wildlife. Therefore there are no TBCs that could be considered as appropriate to apply to human receptors. As this risk assessment is solely concerned with human health and does not consider the potential ecological effects of the chemicals of concern, no further analysis of these standards is necessary.

6.3.2 Location and Action-Specific ARARs

6.3.2.0.1. As mentioned above, location-specific ARARs are restrictions placed on concentrations of chemicals solely because of their presence in a specific location, such as a

wetland or other type of critical habitat. Action-specific requirements are technology- or activity-based requirements or remedial actions at CERCLA sites. Because RAAP does not currently fall under CERCLA regulations, action-specific requirements will not be examined in this section. These ARARs may be examined in more detail in the Corrective Measures Study (CMS) as potential remedial actions are considered.

6.3.2.1 Wetlands

6.3.2.1.1. Wetland communities may be unique or sensitive environments. Research from previous and current investigative activities indicates that jurisdictional wetlands do not occur on the SWMUs under investigation for this RFI, with the exception of drainage features extending to the New River and Stroubles Creek. If a wetland is considered to be under the jurisdictional review of the Clean Water Act, Section 404(b)(1) of the act specifies conditions permitting wetland alterations. These guidelines specifically prohibit activities that cause or contribute to violations of any applicable state water quality standard or that cause significant adverse effects to aquatic life or wildlife from the spread of pollutants through physical, chemical or biological processes.

6.3.2.1.2. General risks to wetland-associated organisms are used as indicators of possible population-level and habitat-level impacts from chemicals of potential concern. There are no chemical-specific standards established specifically for wetlands; however, surface water and sediment criteria used for aquatic communities can be applied to wetlands in the assessment area.

6.3.2.2 Wildlife

6.3.2.2.1. Currently, there are no promulgated or established Federal or Virginia standards relating specific chemical concentrations in soil, sediment or surface water directly to toxic effects on wildlife species. There are abundant toxicological testing data that relate known chemical doses in either food or surface water to acute and chronic effects on test species.

6.4 FATE AND TRANSPORT OF THE CHEMICALS OF POTENTIAL CONCERN

6.4.1 Potential Routes of Migration

6.4.1.1. The primary source for potential release of contaminants to the environment at the RAAP is through the past and present use of SWMUs for waste disposal. The primary release mechanisms from SWMU 17 are the staging and burning of large metallic items in need of explosives decontamination. Release mechanisms for SWMU 31 are deposition of fly ash or bottom ash from former coal burning operations in the settling lagoons. SWMU 48 was used for disposal of oily wastewaters from oil/water separators. The release mechanisms at SWMU 54 are former land disposal of propellant ash and periodic flooding of this area by the New River. These activities have resulted in possible downward infiltration/percolation of rainfall through potentially contaminated surface and subsurface soils, possible surface runoff of contaminated waters, or possible emissions of contaminated fugitive dust. Contaminant infiltration to the subsurface environment can result in groundwater and subsurface soil becoming secondary sources of contamination. Soil in the vadose (unsaturated) and saturated zones can be contaminated by the vertical and horizontal migration of contaminants from surface spills, land application of wastes, or other disposal practices. After migrating through the vadose zone, contaminants can then enter the groundwater where contaminants may undergo hydrolysis, oxidation, reduction, or other processes resulting in the chemical transformation of a contaminant. The contaminants are also attenuated mechanically as they migrate through the subsurface by processes such as dilution, dispersion, diffusion, and absorption. Potential secondary release mechanisms include infiltration and/or percolation of water through contaminated subsurface soil and the discharge of contaminated groundwater to the surface in the form of leachate/seeps. Potential contaminated media can include surficial soil, groundwater, surface water, sediment, or leachate/seeps.

6.4.1.2. Contaminants released to surface water can be transported downstream, dissolved in water or adsorbed on suspended sediment, or can be transported to the atmosphere. Surface runoff can transport contaminants to surface water; fugitive dust generation can transport contaminants to the air; contaminated soil can be tracked from one location to another; plant life may absorb soil contaminants; and wildlife may ingest plants that have assimilated contaminants in leaf and stem tissue. In addition, contaminants can be conveyed by surface water and/or sediments to aquatic life that may be ingested by wildlife.

6.4.1.3. Finally, contaminants can be physically transformed through volatilization or biodegradation or can accumulate in a specific medium. The potential for specific contaminants to migrate from one medium to another or to be transformed is dependent on the physical and chemical properties of each contaminant.

6.4.2 Contaminant Characteristics

6.4.2.1. Evaluating the environmental fate and transport of the chemicals of concern at the SWMUs under investigation was performed to determine the potential for migration in the environment and the potential for human and environmental exposure. The environmental fate and transport of chemicals is dependent upon the physical and chemical properties of the compounds, the environmental transformation processes affecting them, and the media through which they migrate. In this section, the chemical and physical properties of the chemicals of interest are presented, and the relevance of these properties to environmental fate and transport are discussed. Table 6.14 summarizes relevant physical properties of all the chemicals of interest at the RAAP.

6.4.2.2. The water solubility of a substance is a critical property affecting environmental fate. Highly soluble chemicals can be leached rapidly from soils and are generally mobile in groundwater. Solubilities can range from less than 1 mg/L to totally soluble (Lyman et al., 1982). The solubility of chemicals that are not readily soluble in water may be enhanced by the presence of organic solvents (e.g., acetone), which are more soluble in water.

6.4.2.3. The volatilization of a compound depends on its vapor pressure and water solubility. Vapor pressure, a relative measure of the volatility of chemicals in their pure state, varies from approximately 0.001 millimeters of mercury (mm Hg) to 759 mm Hg for liquids. The higher the vapor pressure the greater the volatility. Henry's Law is used to estimate equilibrium vapor pressures of dilute contaminants in water. Compounds with Henry's Law Constants greater than 10^{-3} atmospheres - cubic meter per mole (atm-m^3/mole) can be expected to volatilize readily from water; those with values ranging from 10^{-3} to 10^{-5} atm-m^3/mole are associated with possibly significant volatilization; while compounds with values less than 10^{-5} atm-m^3/mole will volatilize from water only to a limited extent (Lyman et al., 1982).

CAS#	Chemical	GdWtrHalflife (days)	Derm ABS		PC	
7440-38-2	Arsenic	Pers	1%	(c)	1.00E-03	(c)
7440-39-3	Barium	Pers	1%	(c)	1.00E-03	(c)
7440-41-7	Beryllium	Pers	1%	(c)	1.00E-03	(c)
7440-43-9	Cadmium	Pers	1%	(c)	1.00E-03	(c)
7440-47-3	Chromium III	Pers	1%	(c)	1.00E-03	(c)
74399-21-1	Lead	Pers	1%	(c)	1.00E-03	(c)
7439-97-6	Mercury	Pers	1%	(c)	1.00E-03	(c)
7440-02-0	Nickel	Pers	1%	(c)	1.00E-03	(c)
7782-49-2	Selenium	Pers	1%	(c)	1.00E-03	(c)
7440-22-4	Silver	204.0 - 1360.0	10%	(c)	8.10E-01	(c)
56-55-3	Benzo(a)anthracene	720.0 - 1220.0	10%	(c)	1.20E+00	(c)
205-99-2	Benzo(b)fluoranthene	1180.0 - 1300.0	10%	(c)	2.19E+00	(c)
191-24-2	Benzo(g,h,i)perylene	1778.0 - 4280.0	10%	(c)	4.00E+00	(c)
207-08-9	Benzo(k)fluoranthene	10.0 - 389.0	10%	(c)	3.30E-02	(c)
117-81-7	Bis(2-ethylhexyl)phthalate	722.0 - 2000.0	10%	(c)	8.10E-01	(c)
218-01-9	Chrysene	2.0 - 23.0	10%	(c)	3.30E-02	(c)
84-74-2	Di-n-butylphthalate	-	10%	(c)	NR	
534-52-1	4,6-dinitro-2-cresol	6.0 - 112.0	10%	(c)	4.80E-03	(c)
88-99-3	Diethylphthalate	2.0 - 14.0	10%	(c)	1.60E-03	(c)
131-11-3	Dimethylphthalate	280.0 - 880.0	10%	(c)	3.60E-01	(c)
206-44-0	Fluoranthene	-	10%	(c)	6.70E-01	(c)
86-30-6	N-Nitrosodiphenylamine	32.0 - 400.0	10%	(c)	2.70E-01	(c)
85-01-8	Phenanthrene	420.0 - 3800.0	10%	(c)	6.70E-01	(c)
129-00-0	Pyrene	-	25%	(c)	1.00E-03	(c)
56-23-5	Carbon Tetrachloride	56.0 - 1800.0	25%	(c)	8.90E-03	(c)
67-66-3	Chloroform	100.0 - 360.0	25%	(c)	5.30E-03	(c)
75-34-3	1,1-Dichloroethane	56.0 - 132.0	25%	(c)	1.60E-02	(c)
75-35-4	1,1-Dichloroethene	14.0 - 56.0	25%	(c)	4.50E-03	(c)
75-09-2	Methylene chloride	-	25%	(c)	1.00E-03	(c)
98-95-3	Nitrobenzene	-	25%	(c)	1.00E-03	(c)
127-18-4	Tetrachloroethene	140.0 - 546.0	25%	(c)	1.70E-02	(c)
71-55-6	1,1,1-Trichloroethane	321.0 - 1653.0	25%	(c)	1.60E-02	(c)
79-01-6	Trichloroethene	-	1%	(c)	1.00E-03	(c)
2691-41-0	HMX	-	1%	(c)	1.00E-03	(c)
121-14-2	2,4-Dinitrotoluene	-	1%	(c)	1.00E-03	(c)
121-82-4	RDX	-	1%	(c)	1.00E-03	(c)
118-96-7	2,4,6-Trinitrotoluene					

Header Notes:

Class: general analytical classification;

Miscellaneous Abbreviations:

B: biodegradation; H: hydrolysis; M:

V: volatiles; W: wet chemistry; X: ex

Table Notes:

(a) Information gathered from Ground Fate and Exposure Data, Volumes Halflife information gathered from

(b) Gas diffusivity value based upon C where: Gas B diffusivity value =

(c) USEPA, 1992

Table 6.14
Environmental Properties, Fate, and Transport Data[a]
Radford Army Ammunition Plant

CAS#	Chemical	Class	Formula	Mol Wt	Solubility (mg/L)	Vapor Pressure (mm Hg)	Henry's Law K (atm-m3/mole)	Log Kow (mL/g)	Log BCF	Log Koc (mL/g)	Spec Grav	Gas Diff[b] (g/cm²)	SoilHalflife (days)	AirHalflife (days)	SfWtrHalflife (days)	GdWtrHalflife (days)	Derm ABS		PC	
7440-38-2	Arsenic	M	As	74.9	NR	1.00E+00	NR	NR	NR	NR	5.72	NA	Pers	Pers	Pers	Pers	1%	(c)	1.00E-03	(
7440-39-3	Barium	M	Ba	137.0	NR	NR	NR	NR	1.00	NR	3.60	NA	Pers	Pers	Pers	Pers	1%	(c)	1.00E-03	(
7440-41-7	Beryllium	M	Be		Insol	1.00E+01	NR	NR	NR	NR	1.85	NA	Pers	Pers	Pers	Pers	1%	(c)	1.00E-03	(
7440-43-9	Cadmium	M	Cd	112.0	NR	NR	NR	NR	1.91	NR	8.65	NA	Pers	Pers	Pers	Pers	1%	(c)	1.00E-03	(
7440-47-3	Chromium III	M	$Cr^{(+3)}$	52.0	NR	NR	NR	NR	1.20	NR	7.14	NA	Pers	Pers	Pers	Pers	1%	(c)	1.00E-03	(
74399-21-1	Lead	M	Pb	207.0	NR	NR	NR	NR	1.69	4.01	11.34	NA	Pers	Pers	Pers	Pers	1%	(c)	1.00E-03	(
7439-97-6	Mercury	M	Hg	201.0	2.00E+03	2.00E-03	NR	0.71	3.74	1.83	13.53	NA	Pers	Pers	Pers	Pers	1%	(c)	1.00E-03	(
7440-02-0	Nickel	M	Ni	59.0	insol	NR	NR	NR	1.67	NR	8.90	NA	Pers	Pers	Pers	Pers	1%	(c)	1.00E-03	(
7782-49-2	Selenium	M	Se	78.9	Insol	1.00E-03	NR	NR	NR	NR	4.80	NA	Pers	Pers	Pers	Pers	1%	(c)	1.00E-03	(
7440-22-4	Silver	M	Ag	108.0	insol	NR	NR	NR	3.49	NR	10.49	NA	Pers	Pers	Pers	Pers	1%	(c)	1.00E-03	(
56-55-3	Benzo(a)anthracene	S	C18 H12	228.0	1.40E-02	1.10E-07	8.00E-06	5.91	4.00	6.14	1.27	5.08E-02	102.0 - 680.0	0.04 - 0.13	0.04 - 0.13	204.0 - 1360.0	10%	(c)	8.10E-01	(
205-99-2	Benzo(b)fluoranthene	S	C20 H12	252.0	1.20E-03	5.00E-07	1.20E-05	6.57	4.38	5.74	NR	4.83E-02	360.0 - 610.0	0.06 - 0.6	0.36 - 30.0	720.0 - 1220.0	10%	(c)	1.20E+00	(
191-24-2	Benzo(g,h,i)perylene	S	C22 H12	252.0	2.60E-04	1.01E-10	1.40E-07	7.10	4.70	6.89	NR	4.83E-02	590.0 - 650.0	0.01 - 0.13	590.0 - 650.0	1180.0 - 1300.0	10%	(c)	2.19E+00	(
207-08-9	Benzo(k)fluoranthene	S	C20 H12	252.0	5.50E-04	9.59E-11	1.04E-03	6.85	4.53	6.64	NR	4.83E-02	910.0 - 2140.0	0.05 - 0.46	0.16 - 20.8	1778.0 - 4280.0	10%	(c)	4.00E+00	(
117-81-7	Bis(2-ethylhexyl)phthalate	S	C24 H38 O	391.0	4.00E-01	6.20E-08	1.10E-05	4.20	4.14	5.00	0.99	3.88E-02	5.0 - 22.9	0.12 - 1.21	5.0 - 22.9	10.0 - 389.0	10%	(c)	3.30E-02	(
218-01-9	Chrysene	S	C18 H12	228.0	6.00E-03	6.30E-09	7.26E-20	5.91	4.07	5.39	1.27	5.08E-02	371.0 - 1000.0	0.03 - 0.33	0.18 - 0.54	722.0 - 2000.0	10%	(c)	8.10E-01	(
84-74-2	Di-n-butylphthalate	S	C16 H22 O4	278.0	4.50E+03	1.40E-05	6.30E-05	4.79	2.78	3.14	1.04	4.60E-02	2.0 - 23.0	0.31 - 3.08	1.0 - 14.0	2.0 - 23.0	10%	(c)	3.30E-02	(
534-52-1	4,6-dinitro-2-cresol	S	C7 H6 N2 O5	198.1	1.30E+01	1.05E-04	4.80E-11	2.56	1.72	2.48	NR	5.44E-02	-	0.3 - 50.0	0.3 - 58.0	-	10%	(c)	NR	
88-99-3	Diethylphthalate	S	C12 H14 O4	222.0	1.20E+03	3.50E-03	8.46E-07	3.00	2.07	1.84	1.12	5.14E-02	3.0 - 56.0	0.88 - 8.83	3.0 - 56.0	6.0 - 112.0	10%	(c)	4.80E-03	(
131-11-3	Dimethylphthalate	S	C10 H10 O4	194.0	4.50E+04	1.00E-02	2.15E-06	2.00	1.76	2.28	1.19	5.50E-02	1.0 - 7.0	4.67 - 46.7	1.0 - 7.0	2.0 - 14.0	10%	(c)	1.60E-03	(
206-44-0	Fluoranthene	S	C16 H10	202.0	3.73E-01	5.00E-06	1.69E-02	5.22	3.06	4.62	1.25	5.39E-02	140.0 - 440.0	0.08 - 0.84	0.88 - 2.63	280.0 - 880.0	10%	(c)	3.60E-01	(
86-30-6	N-Nitrosodiphenylamine	S	C12 H10 N2 O	198.2	4.00E+01	1.00E-01	6.40E-04	3.13	2.34	3.13	1.23	5.44E-02	-	0.25 - 1.0	-	-	10%	(c)	6.70E-01	(
85-01-8	Phenanthrene	S	C14 H10	178.0	1.29E+00	6.80E-04	2.56E-05	4.57	3.42	4.59	1.18	5.74E-02	16.0 - 200.0	0.08 - 0.84	0.13 - 1.04	32.0 - 400.0	10%	(c)	2.70E-01	(
129-00-0	Pyrene	S	C16 H10	202.0	1.71E-01	2.50E-06	1.87E-05	5.32	2.66	5.13	1.27	5.39E-02	210.0 - 1900.0	0.03 - 0.09	0.03 - 0.09	420.0 - 3800.0	10%	(c)	6.70E-01	(
56-23-5	Carbon Tetrachloride	V	C Cl4	153.2	1.16E+03	9.13E+01	3.04E-02	2.83	1.26	1.85	1.59	6.19E-02	-	10950.0 - 18250.0	3.0 - 30.0	-	25%	(c)	1.00E-03	(
67-66-3	Chloroform	V	C H Cl3	119.0	9.30E+03	1.98E+02	3.20E-03	1.97	0.57	1.64	1.48	7.02E-02	28.0 - 180.0	26.0 - 260.0	28.0 - 180.0	56.0 - 1800.0	25%	(c)	8.90E-03	(
75-34-3	1,1-Dichloroethane	V	C2 H4 Cl2	99.0	8.65E+03	8.70E+01	1.31E-03	1.48	0.08	1.28	1.25	7.70E-02	100.0 - 180.0	12.2 - 121.5	100.0 - 180.0	100.0 - 360.0	25%	(c)	5.30E-03	(
75-35-4	1,1-Dichloroethene	V	C2 H2 Cl2	97.0	6.40E+03	5.91E+02	1.90E-01	2.13	0.75	1.81	1.22	7.78E-02	28.0 - 180.0	0.41 - 4.11	28.0 - 180.0	56.0 - 132.0	25%	(c)	1.60E-02	(
75-09-2	Methylene chloride	V	C H2 Cl2	85.0	1.94E+04	4.40E+02	2.69E-03	1.30	0.70	0.94	1.33	8.31E-02	7.0 - 28.0	19.9 - 191.0	7.0 - 28.0	14.0 - 56.0	25%	(c)	4.50E-03	(
98-95-3	Nitrobenzene	V	C6 H5 N O2	123.1	2.00E+03	1.00E+00	2.20E-05	1.85	0.78	1.84	1.20	6.91E-02	-	0.5 - 111.0	1.0 - 3.8	-	25%	(c)	1.00E-03	(
127-18-4	Tetrachloroethene	V	C2 Cl4	165.8	1.50E+01	1.85E+01	ND	3.40	2.35	ND	1.62	5.95E-02	-	1.0 - 60.0	0.1 - 14.0	-	25%	(c)	1.00E-03	(
71-55-6	1,1,1-Trichloroethane	V	C2 H3 Cl3	134.0	1.33E+03	1.24E+02	1.62E-02	2.49	0.75	2.18	1.34	6.62E-02	28.0 - 180.0	224.7 - 2247.0	140.0 - 273.0	140.0 - 546.0	25%	(c)	1.70E-02	(
79-01-6	Trichloroethene	V	C3 H Cl3	132.0	1.47E+03	7.40E+01	1.17E-02	3.30	1.03	2.10	1.46	6.67E-02	180.0 - 360.0	1.13 - 11.3	180.0 - 360.0	321.0 - 1653.0	25%	(c)	1.60E-02	(
2691-41-0	HMX	X	C4 H8 N8 O8	296.2	NR	NR	NR	NR	NR	NR	NR	4.45E-02	-	-	17.0 - 7900.0	-	1%	(c)	1.00E-03	(
121-14-2	2,4-Dinitrotoluene	X	C7 H6 N2 O4	182.1	3.00E+01	1.40E-04	8.79E-08	1.98	2.31	NR	1.32	5.68E-02	-	1.0 - 71.0	1.7 - 438.0	-	1%	(c)	1.00E-03	(
121-82-4	RDX	X	C3 H6 N6 O6	222.3	Insol	NR	2.60E-11	0.87	1.39	2.22	1.82	5.14E-02	-	0.05 - 1.0	9.0 - 112.0	-	1%	(c)	1.00E-03	(
118-96-7	2,4,6-Trinitrotoluene	X	C7 H5 N2 O4	227.1	ND	1.90E-04	4.57E-07	1.60	ND	3.20	1.65	5.09E-02	-	110.0 - 150.0	25.0 - 64.0	-	1%	(c)	1.00E-03	(

Header Notes:

Class: general analytical classification; BCF: bioconcentration factor (fish); Koc: organic carbon (soils) partition coefficient; Kow: octanol/water partition coefficient; Mol wt: molecular weight; Spec Grav: specific gravity

Miscellaneous Abbreviations:

B: biodegradation; H: hydrolysis; M: metals; O: oxidation; P: photolysis; S: semivolatiles; T1: pesticides; T2: herbicides; T3: polychlorinated biphenyl;
V: volatiles; W: wet chemistry; X: explosives.

Table Notes:

(a) Information gathered from Groundwater Chemicals Desk Reference, Volumes 1 and 2, Montgomery et al. Supplemental information gathered from: The Merck Index, Eleventh Edition; Fate and Exposure Data, Volumes 1 - 3 (Howard, et al, Lewis Publishers); Envirofate Database (Chemical Information System); Estimating Toxicity of Industrial Chemicals to Aquatic Organisms Using SARs, Volume I (USEPA 560/688001). Halflife information gathered from Handbook of Environmental Degradation Rates (Philip Howard, et al, Lewis Publishers, 1991). Miscellaneous halflife and/or degradation rates gathered from Envirofate Database (Chemical Information System).

(b) Gas diffusivity value based upon Graham algorithm as follows: Diffusivity of Gas A = (Diffusivity of Gas B) × (Square root of (Mol Wt of Gas B/Mol Wt of Gas A))
where: Gas B diffusivity value = ethyl ether (0.089 g/cm²) and Gas B mol wt = ethyl ether (74.14 g/mole)

(c) USEPA, 1992

6.4.2.4. The octanol-water partitioning coefficient (K_{ow}) provides a measure of the extent of chemical partitioning between water and octanol at equilibrium. The greater the K_{ow}, the more likely a chemical is to partition to octanol than to remain in water. Octanol is used as a surrogate for lipids (fat); therefore, K_{ow} is used to predict bioconcentration in aquatic organisms.

6.4.2.5. The bioconcentration factor (BCF) measures the extent of chemical partitioning at equilibrium between biological media (e.g., fish or plant tissue) and external environmental media (e.g., water). The higher the BCF, the greater the accumulation in living tissue is likely to be. The organic carbon partition coefficient (K_{oc}) reflects the propensity of a compound to sorb to organic matter found in soil. The normal range of K_{oc} values is 1 to 107 milliliters per gram (ml/g), with higher values indicating greater sorption potential. Chemicals that have a strong tendency to sorb to organic matter (i.e., chemicals with a high K_{oc}) will move more slowly between environmental compartments than chemicals with a low K_{oc}.

6.4.2.6. The molecular weight of a chemical is the sum of the atomic weights of its constituent elements. This property is used in performing calculations for the dermal exposure routes. The specific gravity is the ratio of the mass of a solid or liquid to the mass of an equal volume of distilled water at 4°C.

6.4.2.7. The media-specific half-lives in the last four columns of Table 6.14 provide a relative measure of chemical persistence in a given medium, although actual values can vary greatly depending on site-specific conditions. The greater the half-life, the more persistent the chemical. Half-life properties can be valuable in examining the long-term risks from chemicals at a site and developing remediation alternatives.

6.4.3 Contaminant Migration and Persistence

6.4.3.1. Chemicals detected (explosives, metals, VOCs, polynuclear aromatic hydrocarbons [PAHs]) at RAAP were classified into several categories according to their similarity in chemical structure and/or physiochemical properties (factors that would influence mobility in the environment). The chemical categories and some of the associated elements/compounds within each category are the following:

- Explosives: 2,4,6-trinitrotoluene, HMX, 2,4-dinitrotoluene, and RDX.
- Metals: antimony, arsenic, barium, beryllium, cadmium, chromium, lead, mercury, nickel, selenium, and silver.
- Polynuclear Aromatic Hydrocarbons (PAHs): benzo(a)anthracene, benzo(b)fluoranthene, benzo(g,h,i)perylene, benzo(k)fluoranthene, chrysene, di-n-butyl phthalate, diethylphthalate, dimethylphthalate, fluoranthene, N-nitrosodiphenylamine, phenanthrene and pyrene.
- Volatile Aromatic Hydrocarbons: carbon tetrachloride, chloroform, 1,1-dichloroethane, 1,1-dichloroethylene, methylene chloride, tetrachloroethane, 1,1,1-trichloroethane, and trichloroethylene.

6.4.3.2. Based on the chemical and physical characteristics of chemicals potentially present at the RAAP, the following generalizations regarding environmental fate and transport can be made to provide a relative comparison to other chemical categories.

6.4.3.3. PAHs and explosives have a high affinity for organic matter and low water solubility. Water solubility tends to decrease, and affinity for organic material tends to increase with increasing molecular weight. When present in soil or sediments, PAHs and explosives tend to remain bound to the soil particles and dissolve only slowly into groundwater or the overlying water column. Because of the high affinity for organic matter, the physical fate of these chemicals is usually controlled by the transport of particulates. Thus, soil, sediment, and suspended particulate matter (in air) represent important media for chemical transport. Furthermore, because of their high affinity for organic matter, PAHs are readily bioaccumulated by living organisms; whereas, explosives are not as readily bioaccumulated.

6.4.3.4. Metals of potential concern identified at the RAAP are generally immobile under the subsurface conditions at the site. Soils and geological maps discussed in Section 3 of this report generally show that the upland regions of this facility are underlain by clay-rich residuum. Slightly acid to neutral soil pH and oxidizing conditions are expected for soils throughout the RAAP.

6.4.3.5. Under such conditions, cadmium exists as cations and can be adsorbed onto the clays. Chromium and selenium have several oxidation states and form anionic complexes; these complexes readily precipitate by reaction with iron and other cations. These chemical

properties result in these metals being immobile under the environmental conditions present at the RAAP.

6.4.3.6. In groundwater or wet soils in the unsaturated zone under the site conditions, antimony is expected to behave like arsenic (Hem, 1985). A low solubility is expected due to coprecipitation of the arsenate anion with iron species in the soil. Therefore, antimony is also considered to be relatively immobile under site conditions.

6.4.3.7. The equilibrium solubility of beryllium in dilute water at pH 6 is very low, near 100 μg/L (Hem, 1985). The behavior of mercury in the soil is impossible to predict without knowledge of the local environment. In the absence of chloride ions, the most probable dissolved species is the relatively soluble $Hg(OH)_2$, a neutral species (Stumm and Morgan, 1981). However, if the mercury occurs as the metallic element, it readily volatilizes or it precipitates in the presence of sulfur.

6.4.3.8. Volatile organic compounds tend to have a low residence time in surface soil and surface water environments. These chemicals can be persistent in groundwater. However, there is evidence that non-chlorinated volatile organic compounds may degrade rapidly in the vadose zone above groundwater plumes.

6.5 RISK ASSESSMENT METHODOLOGY

6.5.1 Exposure Assessment

6.5.1.0.1. Under current USEPA guidelines (USEPA, 1989c), the assessment of human exposure to the selected chemicals of concern at sites contaminated with potentially toxic constituents is carried out in three steps:

- Characterization of exposure setting (i.e., relevant physical characteristics of the site and potentially exposed populations);
- Identification and evaluation of pathways by which the previously identified populations may become exposed; and
- Quantification of the exposure (i.e., estimation of exposure point concentrations and human intake of contaminants).

6.5.1.0.2. Relevant physical characteristics of each SWMU or area of concern are discussed in Sections 7 through 12. The remaining items are discussed below.

6.5.1.1 Identification of Potential Receptors

6.5.1.1.1. Demographics, groundwater and surface water use, and ecological characteristics of each SWMU are necessary to identify potential receptors and pathways of contamination exposure. Land use at RAAP will be assumed to remain industrial for future exposure assessment. This is due primarily to RAAP being the only active propellant and explosive manufacturing facility in the United States. Therefore, future receptors will not differ from the current receptors.

6.5.1.1.2 **Local Demographics** - The area surrounding RAAP is mostly rural with the natural terrain prohibiting extensive development. The closest residential community is Fairlawn, located approximately 3 miles southwest of RAAP. The City of Radford is located approximately 5 miles southwest of the facility, and has an estimated 1990 population of 15,940 (Virginia Population Projections, 1993). For a more complete discussion of demographics, refer to Table 3.3 in Section 3.3.

6.5.1.1.3. The 4 SWMUs under investigation at RAAP under this RFI are located within the facility boundaries, which at present limits access to these areas to official visitors. However, the general public has access to the New River which flows through the installation and near several SWMUs under investigation (31, 48 and 54). The New River is separated from RAAP by a security fence which limits direct contact between recreational users of the river and potentially contaminated soils and waters at these SWMUs; however, SWMU 54 lies outside of this fence and is accessible from the New River. People boating, fishing or swimming in the river could be exposed to contaminants migrating through surface water runoff. In addition, burning operations conducted at SWMU 17 may contribute to the inhalation of airborne contaminants by human receptors.

6.5.1.1.4 **Groundwater Receptors** - According to previous investigations at this facility (ES, 1994a), there are two known supply wells at this installation. Well number 1 is located within the Horseshoe adjacent to the New River Bridge and is currently not in use. Well number 2 is located in the southeast corner of the site and is inactive, but may be used as a

backup potable water supply for the U.S. Army Research, Development and Acquisition Information Systems Agency.

6.5.1.1.5. At SWMU 17, the direction of groundwater flow is generally toward the New River. Groundwater which recharges the aquifer at the SWMU 17 area discharges into the New River. Groundwater has been shown to flow westward through a direct conduit linking SWMU 17A with a spring at the New River, as discussed in Subsection 7.4 of this report. The closest supply well is over one mile away and upgradient. The other supply well is separated from SWMU 17 by the New River. At SWMUs 31, 48 and 54, potentiometric surface maps indicate that groundwater flows toward the New River. The wells are positioned such that no SWMU is located between a supply well and the New River. Some residents of Blacksburg rely on groundwater as their potable water supply, but these supply wells are located approximately 5 miles east of RAAP. The shallow groundwater for many of the SWMUs flows toward the New River and would not likely migrate toward any users in the vicinity of RAAP.

6.5.1.1.6 **Surface Water Receptors** - Drinking water used at RAAP comes from two surface water intakes on the New River: one located approximately 2 miles upstream of the mouth of Stroubles Creek and the other approximately 6 miles downstream of Stroubles Creek. The Commonwealth of Virginia has classified Stroubles Creek and the portion of the New River flowing through RAAP as generally satisfactory for beneficial use, which includes public or municipal water supply, secondary contact recreation and propagation of fish and wildlife. All water used at RAAP is taken from the New River. Current surface water receptors include recreational users of this stretch of the New River and plant personnel.

6.5.1.1.7. **Soil Receptors** - Receptors could be exposed to surface soils through inhalation of particulates and volatiles, incidental ingestion and dermal contact. Exposure to surface soils at these sites may be limited where there is excessive vegetative cover or the site is paved or covered. Most of SWMU 17 is neither paved nor vegetated which provides a potentially complete pathway for current site workers. Human exposure may be limited at SWMU 48 because the site is currently inactive. SWMU 54 is partially vegetated, but there are areas where ash is exposed through the soil. Current soil receptors include site workers and hunters who may travel across contaminated soils. Future soil receptors include site workers.

6.5.1.1.8 **Air Receptors** - Since SWMU 17 is an active waste burning area, air emissions are a concern from this site. These emissions and contaminated dust would likely be carried over human receptors at RAAP and the surrounding communities. However, ambient air monitoring data during burning operations is unavailable and therefore risks associated with this activity are not quantifiable. Air emissions from SWMUs 40, 48 and 54 would be limited to volatilization of contaminants from the surface soils and fugitive dust emissions. Currently, due to the location of these SWMUs, this would affect mainly site workers and official visitors to RAAP. The sediments at SWMU 31 are covered with water and this limits fugitive emissions from this site.

6.5.1.2 Identification of Exposure Pathways

6.5.1.2.1. An assessment of exposure pathways is based on the current and potential future site conditions, an evaluation of the contaminants of concern, and an evaluation of the potential current and future receptors. An exposure pathway describes how a population can be exposed to chemicals at a site. As stated in Section 6.1.2, a completed exposure pathway comprises the following elements:

- A source and mechanism for chemical release;
- An environmental transport medium;
- An exposure point; and
- A human receptor and a feasible route of exposure at the exposure point.

A pathway is not complete unless each element is present.

6.5.1.2.2. Exposure point concentrations and daily uptake for each contaminant of concern are estimated for each potential exposure pathway. The pathways selected for quantitative analysis include those that are considered to represent the greatest potential for human exposure. Pathways that are less significant are identified and discussed, but not quantified.

6.5.1.2.3. The pathways evaluated were potential current exposure of site workers, construction workers, recreational users, hunters and fishermen to surface water, sediments and surface soils, and future exposure of site workers to groundwater. Current site workers were evaluated for exposure to surface soils through ingestion, dermal contact, and inhalation of

volatiles and particulates, and surface water and sediments through ingestion and dermal contact. Current construction workers were evaluated for exposure to surface and subsurface soils through ingestion, dermal contact and inhalation of volatiles and particulates, and surface waters and sediments through ingestion and dermal contact. Current recreational users and fishermen were evaluated for incidental ingestion and dermal contact with surface waters. Current hunters were evaluated for incidental ingestion and dermal contact with surface soils.

6.5.1.2.4. In order to be consistent with the assumptions concerning future land use at RAAP, the only future exposure scenario evaluated that differs from current exposure scenarios was future site worker exposure to groundwater through ingestion, dermal contact and inhalation of volatiles while showering. Although this exposure scenario is unlikely because all drinking water used at RAAP is obtained from the New River, this scenario allows a quantification of the risks from exposure to site groundwater.

6.5.1.3 Quantification of Exposure Pathways

6.5.1.3.1. Exposure-point concentrations were estimated for pathways selected for quantitative evaluation and pathway-specific human intakes were quantified. Exposure-point concentrations can be based on measured monitoring data or on modeling results. For this risk assessment, exposure-point concentrations were calculated from monitoring data. To provide a conservative basis for the risk assessment, steady-state conditions were assumed. Therefore, current and future chemical concentrations were assumed to be identical.

6.5.1.3.2. Intakes are normally expressed as the amount of chemical intake in milligrams of chemical per kilogram of body weight per day (mg/kg-day), which represents an intake normalized for body weight over time. The total exposure is divided by the time period of interest to obtain an average exposure over time. The averaging time is a function of the toxic endpoint: for non-carcinogenic effects it is the exposure duration multiplied by 365 days per year, and for carcinogenic effects it is the lifetime (70 years) multiplied by 365 days per year.

6.5.1.3.3. Exposure/intake variables were used to estimate the reasonable maximum exposure (RME). As defined by USEPA, the RME is considered the highest reasonable exposure that is to be expected to occur at the site. The intent of the RME is to estimate a conservative exposure case which is above the average exposure and within the range of

possible exposures. The selection of the parameters to evaluate all exposure scenarios is based on the current use of each site and the potential future use of the sites. These estimates of exposure should not be mistaken for actual exposures occurring at each site. RME values presented in Risk Assessment Guidance for Superfund, Volume I, Human Health Evaluation Manual, Supplemental Guidance, Standard Default Exposure Factors (USEPA, 1991) are used when available for all scenarios. Examples of these default parameters include 1) a 70 year life span, 2) a body weight of 70 kg, and 3) an inhalation rate of 20 cubic meters per day. In the absence of standard assumptions and site-specific information, exposure was estimated using best professional judgment and available site information. Detailed intake algorithms for each exposure scenario, by media and exposure route, are shown in Tables 6.15 through 6.35.

6.5.1.3.4 In addition to evaluating receptors for RME scenarios, the Central Tendency (CT) exposure scenarios were also evaluated. CT default exposure parameters are values that are based on average exposure values and are considered most representative of an exposure that would be contacted at a site over an extended period of time. Therefore, these exposure scenarios can be evaluated based upon average and maximum site contact.

6.5.1.3.5. The emphasis in risk assessments conducted under USEPA Superfund guidance is on chronic exposures unless specific conditions warrant a short-term or an acute assessment. The focus of this evaluation is long-term exposure to relatively low chemical concentrations (i.e., chronic exposure).

TABLE 6.15

EXPOSURE PARAMETERS AND INTAKE ALGORITHM FOR CURRENT SITE WORKER EXPOSURE: SURFACE SOIL INGESTION

RADFORD ARMY AMMUNITION PLANT RADFORD, VIRGINIA

$$\text{Intake (mg/kg-day)} = \frac{C \times IR \times EF \times ED \times CF \times FI}{BW \times AT}$$

	Parameter	CT	RME
C =	Chemical Concentration in Soil (mg/kg)	(a)	(b)
IR =	Ingestion Rate (mg/day)	50	100
EF =	Exposure Frequency (days/year)	125(c)	250
ED =	Exposure Duration (years)	5(d)	25
CF =	Conversion Factor (kg/mg)	10^{-6}	10^{-6}
FI =	Fraction Ingested (unitless)	1	1
BW =	Body Weight (kg)	70	70
AT =	Averaging Time (days)		
	Noncarcinogenic	1,825	9,125
	Carcinogenic	25,550	25,550

Source: Superfund's Standard Default Exposure Factors for the Central Tendency and Reasonable Maximum Exposure (USEPA, 1993).

CT = Central Tendency
RME = Reasonable Maximum Exposure
(a) = Lower of the 95% upper confidence limit of the mean or the maximum detected value.
(b) = Higher of the 95% upper confidence limit of the mean or the maximum detected value.
(c) = Best professional judgment based on Virginia climate; outside work was assumed likely for 1/2 of year.
(d) = Bureau of Labor Statistics (USEPA, 1990).

TABLE 6.16

EXPOSURE PARAMETERS AND INTAKE ALGORITHM FOR CURRENT SITE WORKER EXPOSURE: SURFACE SOIL DERMAL CONTACT

RADFORD ARMY AMMUNITION PLANT RADFORD, VIRGINIA

$$\text{Intake (mg/kg-day)} = \frac{C \times SA \times AF \times EF \times ED \times CF}{BW \times AT}$$

Parameter		CT	RME
C =	Chemical Concentration in Soil (mg/kg)	(a)	(b)
SA =	Skin Area (cm2/event) (c)	3,160	4,100
AF =	Sin Adherence Factor (mg/cm^2)	1	1
EF =	Exposure Frequency (days/year)	125(d)	250
ED =	Exposure Duration (years)	5(e)	25
CF =	Conversion Factor (kg/mg)	10^{-6}	10^{-6}
BW =	Body Weight (kg)	70	70
AT =	Averaging Time (days)		
	Noncarcinogenic	1,825	9,125
	Carcinogenic	25,550	25,550

Source: Superfund's Standard Default Exposure Factors for the Central Tendency and Reasonable Maximum Exposure (USEPA, 1993).

CT = Central Tendency
RME = Reasonable Maximum Exposure
(a) = Lower of the 95% upper confidence limit of the mean or the maximum detected value.
(b) = Higher of the 95% upper confidence limit of the mean or the maximum detected value.
(c) = Head, forearms and hands: CT = Mean values and Upper Bound = Maximum values.
(d) = Best professional judgment based on Virginia climate; work outdoors was assumed likely 1/2 of the year.
(e) = Bureau of Labor Statistics (USEPA, 1990).

TABLE 6.17

EXPOSURE PARAMETERS AND INTAKE ALGORITHM FOR CURRENT SITE WORKER EXPOSURE: INHALATION OF SURFACE SOIL VOLATILES AND PARTICULATES

RADFORD ARMY AMMUNITION PLANT
RADFORD, VIRGINIA

$$\text{Intake (mg/kg-day)} = \frac{C \times IR \times EF \times ED \times [1/PEF \text{ or } 1/VF]}{BW \times AT}$$

Parameter		CT	RME
C =	Chemical Concentration in Soil (mg/kg)	(a)	(b)
IR =	Inhalation Rate (m^3/hour)	2.0	3.5
ET =	Exposure Time (hours/day)	8	8
EF =	Exposure Frequency (days/year)	125(c)	250
ED =	Exposure Duration (years)	5(d)	25
PEF =	Particulate Emission Factor (m^3/kg)	site specific	site specific
VF =	Volatilization Factor (m^3/kg)	chemical specific	chemical specific
BW =	Body Weight (kg)	70	70
AT =	Averaging Time (days)		
	Noncarcinogenic	1,825	9,125
	Carcinogenic	25,550	25,550

Source: Superfund's Standard Default Exposure Factors for the Central Tendency and Reasonable Maximum Exposure (USEPA, 1993).

CT = Central Tendency
RME = Reasonable Maximum Exposure
(a) = Lower of the 95% upper confidence limit of the mean or the maximum detected value.
(b) = Higher of the 95% upper confidence limit of the mean or the maximum detected value.
(c) = Best professional judgment based on Virginia climate; work outdoors was assumed likely 1/2 of the year.
(d) = Bureau of Labor Statistics (USEPA, 1990).

TABLE 6.18

EXPOSURE PARAMETERS AND INTAKE ALGORITHM FOR CURRENT SITE WORKER EXPOSURE: INGESTION OF SURFACE WATER

RADFORD ARMY AMMUNITION PLANT RADFORD, VIRGINIA

$$\text{Intake (mg/kg-day)} = \frac{C \times IR \times EF \times ED \times CF}{BW \times AT}$$

Parameter		CT	RME
C =	Chemical Concentration in Water (mg/L)	(a)	(b)
IR =	Ingestion Rate (L/day)	0.05(c)	0.05(c)
CF =	Conversion Factor (L/L)	1	1
EF =	Exposure Frequency - New River (days/year)	25(d)	50(e)
EF =	Exposure Frequency - Stroubles Creek (days/year)	25(d)	50(e)
ED =	Exposure Duration (years)	5(f)	25
BW =	Body Weight (kg)	70	70
AT =	Averaging Time (days)		
	Noncarcinogenic	1,825	9,125
	Carcinogenic	25,550	25,550

Source: Superfund's Standard Default Exposure Factors for the Central Tendency and Reasonable Maximum Exposure (USEPA, 1993).

CT = Central Tendency.
RME = Reasonable Maximum Exposure.
(a) = Lower of the 95% upper confidence limit of the mean or the maximum detected value.
(b) = Higher of the 95% upper confidence limit of the mean or the maximum detected value.
(c) = Best professional judgment.
(d) = Best professional judgment. Assume work near creek or river once per week.
(e) = Best professional judgment. Assume work near creek or river twice per week.
(f) = Bureau of Labor Statistics (USEPA, 1990).

TABLE 6.19

EXPOSURE PARAMETERS AND INTAKE ALGORITHM FOR CURRENT SITE WORKER EXPOSURE: DERMAL CONTACT WITH SURFACE WATER

RADFORD ARMY AMMUNITION PLANT RADFORD, VIRGINIA

$$\text{Intake (mg/kg-day)} = \frac{C \times SA \times EF \times PC \times ED \times ET \times CF}{BW \times AT}$$

Parameter		CT	RME
C	= Chemical Concentration in Water (mg/L)	(a)	(b)
SA	= Skin Surface Area (cm^2)	840(c)	1,130(c)
CF	= Conversion Factor (L/cm^3)	0.001	0.001
EF	= Exposure Frequency - New River (days/year)	25(d)	50(e)
EF	= Exposure Frequency - Stroubles Creek (days/year)	25(d)	50(e)
PC	= Permeability Constant (cm/hr)	chemical -specific	chemical-specific
ED	= Exposure Duration (years)	5(f)	25
ET	= Exposure Time (hrs/day)	0.15(g)	0.15(g)
BW	= Body Weight (kg)	70	70
AT	= Averaging Time (days)		
	Noncarcinogenic	1,825	9,125
	Carcinogenic	25,550	25,550

Source: Superfund's Standard Default Exposure Factors for the Central Tendency and Reasonable Maximum Exposure (USEPA, 1993).

CT = Central Tendency
RME = Reasonable Maximum Exposure
(a) = Lower of the 95% upper confidence limit of the mean or the maximum detected value.
(b) = Higher of the 95% upper confidence limit of the mean or the maximum detected value.
(c) = Hands: CT = Mean values and RME = Maximum values.
(d) = Best professional judgment. Assume work near creek or river once per week.
(e) = Best professional judgment. Assume work near creek or river twice per week.
(f) = Bureau of Labor Statistics (USEPA, 1990).
(g) = Best Professional Judgment.

TABLE 6.20

EXPOSURE PARAMETERS AND INTAKE ALGORITHM FOR CURRENT SITE WORKER EXPOSURE: SEDIMENT INGESTION

RADFORD ARMY AMMUNITION PLANT RADFORD, VIRGINIA

$$\text{Intake (mg/kg-day)} = \frac{C \times IR \times EF \times ED \times CF \times FI}{BW \times AT}$$

	Parameter	CT	RME
C =	Chemical Concentration in Sediment (mg/kg)	(a)	(b)
IR =	Ingestion Rate (mg/day)	50	100
EF =	Exposure Frequency - New River (days/year)	25(c)	50(d)
EF =	Exposure Frequency - Stroubles Creek (days/year)	25(c)	50(d)
ED =	Exposure Duration (years)	5(e)	25
CF =	Conversion Factor (kg/mg)	10^{-6}	10^{-6}
FI =	Fraction Ingested (unitless)	1	1
BW =	Body Weight (kg)	70	70
AT =	Averaging Time (days)		
	Noncarcinogenic	1,825	9,125
	Carcinogenic	25,550	25,550

Source: Superfund's Standard Default Exposure Factors for the Central Tendency and Reasonable Maximum Exposure (USEPA, 1993).

CT = Central Tendency
RME = Reasonable Maximum Exposure
(a) = Lower of the 95% upper confidence limit of the mean or the maximum detected value.
(b) = Higher of the 95% upper confidence limit of the mean or the maximum detected value.
(c) = Best professional judgment. Assume work near creek or river once per week.
(d) = Best professional judgment. Assume work near creek or river twice per week
(e) = Bureau of Labor Statistics (USEPA, 1990).

TABLE 6.21

EXPOSURE PARAMETERS AND INTAKE ALGORITHM FOR CURRENT SITE WORKER EXPOSURE: SEDIMENT DERMAL CONTACT

RADFORD ARMY AMMUNITION PLANT RADFORD, VIRGINIA

$$\text{Intake (mg/kg-day)} = \frac{C \times SA \times AF \times EF \times ED \times CF}{BW \times AT}$$

	Parameter	CT	RME
C =	Chemical Concentration in Sediment (mg/kg)	(a)	(b)
SA =	Skin Area (cm2/event) (c)	840(c)	1,130(c)
AF =	Skin Adherence Factor (mg/cm^2)	1	1
EF =	Exposure Frequency - New River (days/year)	25(d)	50(e)
EF =	Exposure Frequency - Stroubles Creek (days/year)	25(d)	50(e)
ED =	Exposure Duration (years)	5(f)	25
CF =	Conversion Factor (kg/mg)	10^{-6}	10^{-6}
BW =	Body Weight (kg)	70	70
AT =	Averaging Time (days)		
	Noncarcinogenic	1,825	9,125
	Carcinogenic	25,550	25,550

Source: Superfund's Standard Default Exposure Factors for the Central Tendency and Reasonable Maximum Exposure (USEPA, 1993).

CT = Central Tendency
RME = Upper Bound Exposure
(a) = Lower of the 95% upper confidence limit of the mean or the maximum detected value.
(b) = Higher of the 95% upper confidence limit of the mean or the maximum detected value.
(c) = Hands: CT = Mean values and RME = Maximum values.
(d) = Best professional judgment. Assume work near creek or river once per week.
(e) = Best professional judgment. Assume work near creek or river twice per week.
(f) = Bureau of Labor Statistics (USEPA, 1990).

TABLE 6.22

EXPOSURE PARAMETERS AND INTAKE ALGORITHM FOR CURRENT RECREATIONAL SURFACE WATER USERS: INGESTION OF CHEMICALS IN SURFACE WATER WHILE SWIMMING

RADFORD ARMY AMMUNITION PLANT RADFORD, VIRGINIA

$$\text{Intake (mg/kg-day)} = \frac{C \times CR \times ET \times EF \times ED}{BW \times AT}$$

Parameter	CT	RME
C = Chemical Concentration in Water (mg/L)	(a)	(b)
CR = Contact Rate (L/hr)	0.05(c)	0.05(c)
ET = Exposure Time (hr/day)(d)	0.013(e)	0.11(f)
EF = Exposure Frequency (day/yr)	3(g)	7(h)
ED = Exposure Duration (years)	9(i)	30
BW = Body Weight (kg)	70	70
AT = Averaging Time (days)		
Noncarcinogenic	3,285	10,950
Carcinogenic	25,550	25,550

Source: Superfund's Standard Default Exposure Factors for the Central Tendency and Reasonable Maximum Exposure (USEPA, 1993).

CT = Central Tendency
RME = Reasonable Maximum Exposure
(a) = Lower of the 95% upper confidence limit of the mean or the maximum detected value.
(b) = Higher of the 95% upper confidence limit of the mean or the maximum detected value.
(c) = USEPA 1989d.
(d) = Based on total outdoor leisure time for men and women. USEPA 1989.
(e) = 10% of mean active leisure time outdoors.
(f) = 10% of upper bound active leisure time outdoors computed as mean + 2 standard deviations.
(g) = Best professional judgment.
(h) = National swimming average, USEPA 1989d
(i) = National median time at one residence USEPA 1989.

TABLE 6.23

EXPOSURE PARAMETERS AND INTAKE ALGORITHM FOR CURRENT RECREATIONAL SURFACE WATER USERS: DERMAL CONTACT WITH CHEMICALS IN SURFACE WATER WHILE SWIMMING

RADFORD ARMY AMMUNITION PLANT RADFORD, VIRGINIA

$$\text{Intake (mg/kg-day)} = \frac{C \times SA \times ET \times PC \times EF \times ED \times CF}{BW \times AT}$$

Parameter	CT	RME
C = Chemical Concentration in Water (mg/L)	(a)	(b)
SA = Skin Surface Area (cm^2)	19,400(c)	22,800(c)
ET = Exposure Time (hours/day) (d)	0.013(e)	0.11(f)
EF = Exposure Frequency (days/yr)	3(g)	7(h)
PC = Permeability Constant (cm/hr)	chemical-specific	chemical-specific
ED = Exposure Duration (years)	9(i)	30
CF = Volumetric Conversion Factor (liter/cm^3)	0.001	0.001
BW = Body Weight (Kg)	70	70
AT = Averaging Time (days)		
Noncarcinogenic	3,285	10,950
Carcinogenic	25,550	25,550

Source: Superfund's Standard Default Exposure Factors for the Central Tendency and Reasonable Maximum Exposure (1993).
CT = Central Tendency
RME = Reasonable Maximum Exposure

TABLE 6.24

EXPOSURE PARAMETERS AND INTAKE ALGORITHM FOR INCIDENTAL INGESTION OF SURFACE WATER BY FISHERMAN

RADFORD ARMY AMMUNITION PLANT RADFORD, VIRGINIA

$$\text{Intake (mg/kg-day)} = \frac{C \times CR \times ET \times EF \times ED}{BW \times AT}$$

Parameter	CT	RME
C = Chemical Concentration in Water (mg/L)	(a)	(b)
CR = Contact Rate (L/hr)	0.0005(c)	0.0005(c)
ET = Exposure Time (hr/day)(d)	1(d)	8(d)
EF = Exposure Frequency (day/yr)	32(e)	144(f)
ED = Exposure Duration (years)	9(g)	50(d)
BW = Body Weight (kg)	70	70
AT = Averaging Time (days)		
Noncarcinogenic	3,285	18,250
Carcinogenic	25,550	25,550

Source: Superfund's Standard Default Exposure Factors for the Central Tendency and Reasonable Maximum Exposure (USEPA, 1993).

CT = Central Tendency
RME = Reasonable Maximum Exposure
(a) = Lower of the 95% upper confidence limit of the mean or the maximum detected value.
(b) = Higher of the 95% upper confidence limit of the mean or the maximum detected value.
(c) = Best professional judgment - 1% of water ingestion rate for swimming.
(d) = Best professional judgment.
(e) = Best professional judgment. 1 day/week for 6 months/yr + 1 day/month for 6 months/yr.
(f) = Best professional judgment. 5 days/week for 6 months/yr + 1 day/wk for 6 months/yr.
(g) = National median time at one residence USEPA 1989.

TABLE 6.25

EXPOSURE PARAMETERS AND INTAKE ALGORITHM FOR DERMAL CONTACT WITH SURFACE WATER BY FISHERMAN

RADFORD ARMY AMMUNITION PLANT RADFORD, VIRGINIA

$$\text{Intake (mg/kg-day)} = \frac{C \times SA \times ET \times PC \times EF \times ED \times CF}{BW \times AT}$$

Parameter	CT	RME
C = Chemical Concentration in Water (mg/L)	(a)	(b)
SA = Skin Surface Area (cm^2)	3,160(c)	4,100(c)
ET = Exposure Time (hours/day) (d)	1(d)	8(d)
EF = Exposure Frequency (days/yr)	32(e)	144(f)
PC = Permeability Constant (cm/hr)	chemical-specific	chemical-specific
ED = Exposure Duration (years)	9(g)	50(d)
CF = Volumetric Conversion Factor (liter/cm^3)	0.001	0.001
BW = Body Weight (kg)	70	70
AT = Averaging Time (days)		
Noncarcinogenic	3,285	18,250
Carcinogenic	25,550	25,550

Source: Superfund's Standard Default Exposure Factors for the Central Tendency and Reasonable Maximum Exposure (USEPA, 1993).

CT = Central Tendency
RME = Reasonable Maximum Exposure
(a) = Lower of the 95% upper confidence limit of the mean or the maximum detected value.
(b) = Higher of the 95% upper confidence limit of the mean or the maximum detected value.
(c) = Head, forearms and hands: CT = Mean values, RME = Maximum values.
(d) = Best professional judgment.
(e) = Best professional judgment. 1 day/week for 6 months/yr + 1 day/month for 6 months/yr.
(f) = Best professional judgment. 5 days/week for 6 months/yr + 1 day/wk for 6 months/yr.
(g) = National median time at one residence USEPA 1989.

TABLE 6.26

EXPOSURE PARAMETERS AND INTAKE ALGORITHM FOR RECREATIONAL HUNTER EXPOSURE: SURFACE SOIL INGESTION

RADFORD ARMY AMMUNITION PLANT RADFORD, VIRGINIA

$$\text{Intake (mg/kg-day)} = \frac{C \times IR \times EF \times ED \times CF \times FI}{BW \times AT}$$

Parameter	CT	RME
C = Chemical Concentration in Soil (mg/kg)	(a)	(b)
IR = Ingestion Rate (mg/day)	50	100
EF = Exposure Frequency (days/year)	25(c)	39(d)
ED = Exposure Duration (years)	9(e)	50(f)
CF = Conversion Factor (kg/mg)	10^{-6}	10^{-6}
FI = Fraction Ingested (unitless)	1	1
BW = Body Weight (kg)	70	70
AT = Averaging Time (days)		
Noncarcinogenic	3,285	18,250
Carcinogenic	25,550	25,550

Source: Superfund's Standard Default Exposure Factors for the Central Tendency and Reasonable Maximum Exposure (USEPA, 1993).

CT = Central Tendency
RME = Reasonable Maximum Exposure
(a) = Lower of the 95% upper confidence limit of the mean or the maximum detected value.
(b) = Higher of the 95% upper confidence limit of the mean or the maximum detected value.
(c) = Assumption of 1 day/week for duration of bow season for deer hunting which lasts for 5 months.
(d) = Assumption of 2 weeks vacation and 1 day/week for 5 months.
(e) = National median time at one residence USEPA 1989.
(f) = Best professional judgment.

TABLE 6.27

EXPOSURE PARAMETERS AND INTAKE ALGORITHM FOR RECREATIONAL HUNTER EXPOSURE: SURFACE SOIL DERMAL CONTACT

RADFORD ARMY AMMUNITION PLANT RADFORD, VIRGINIA

$$\text{Intake (mg/kg-day)} = \frac{C \times SA \times AF \times EF \times ED \times CF}{BW \times AT}$$

Parameter		CT	RME
C	= Chemical Concentration in Soil (mg/kg)	(a)	(b)
SA	= Skin Area (cm^2/event)	3,160(c)	4,100(c)
AF	= Skin Adherence Factor (mg/cm^2)	1	1
EF	= Exposure Frequency (days/year)	25(d)	39(e)
ED	= Exposure Duration (years)	9(f)	50(g)
CF	= Conversion Factor (kg/mg)	10^{-6}	10^{-6}
BW	= Body Weight (kg)	70	70
AT	= Averaging Time (days)		
	Noncarcinogenic	3,285	18,250
	Carcinogenic	25,550	25,550

Source: Superfund's Standard Default Exposure Factors for the Central Tendency and Reasonable Maximum Exposure (1993).

CT = Central Tendency
RME = Reasonable Maximum Exposure
(a) = Lower of the 95% upper confidence limit of the mean or the maximum detected value.
(b) = Higher of the 95% upper confidence limit of the mean or the maximum detected value.
(c) = Head, arms and hands. CT = Mean values, RME = Maximum values.
(d) = Assumption of 1 day/week for duration of bow season for deer hunting which lasts for 5 months.
(e) = Assumption of 2 weeks vacation and 1 day/week for 5 months.
(f) = National median time at one residence USEPA 1989.
(g) = Best professional judgment.

TABLE 6.28

EXPOSURE PARAMETERS AND INTAKE ALGORITHM FOR FUTURE SITE WORKER EXPOSURE: INGESTION OF GROUNDWATER

RADFORD ARMY AMMUNITION PLANT RADFORD, VIRGINIA

$$\text{Intake (mg/kg-day)} = \frac{C \times IR \times EF \times ED \times CF}{BW \times AT}$$

Parameter		CT	RME
C =	Chemical Concentration in Water (mg/L)	(a)	(b)
IR =	Ingestion Rate (L/day)	0.5	1
CF =	Conversion Factor (L/L)	1	1
EF =	Exposure Frequency (days/year)	125	250
ED =	Exposure Duration (years)	5(c)	25
BW =	Body Weight (kg)	70	70
AT =	Averaging Time (days)		
	Noncarcinogenic	1,825	9,125
	Carcinogenic	25,550	25,550

Source: Superfund's Standard Default Exposure Factors for the Central Tendency and Reasonable Maximum Exposure (USEPA, 1993).

CT = Central Tendency
RME = Reasonable Maximum Exposure
(a) = Lower of the 95% upper confidence limit of the mean or the maximum detected value.
(b) = Higher of the 95% upper confidence limit of the mean or the maximum detected value.
(c) = Bureau of Labor Statistics (USEPA, 1990).

TABLE 6.29

EXPOSURE PARAMETERS AND INTAKE ALGORITHM FOR FUTURE SITE WORKER EXPOSURE: DERMAL CONTACT WITH GROUNDWATER

RADFORD ARMY AMMUNITION PLANT RADFORD, VIRGINIA

$$\text{Intake (mg/kg-day)} = \frac{C \times SA \times EF \times PC \times ED \times ET \times CF}{BW \times AT}$$

Parameter		CT	RME
C	= Chemical Concentration in Water (mg/L)	(a)	(b)
SA	= Skin Surface Area (cm^2)	19,400(c)	22,800(c)
CF	= Volumetric Conversion Factor (L/cm^3)	0.001	0.001
EF	= Exposure Frequency (days/year)	125	250
PC	= Permeability Constant (cm/hr)	chemical-specific	chemical-specific
ED	= Exposure Duration (years)	5(d)	25
ET	= Exposure Time (hrs/day)	0.117(e)	0.2(f)
BW	= Body Weight (kg)	70	70
AT	= Averaging Time (days)		
	Noncarcinogenic	1,825	9,125
	Carcinogenic	25,550	25,550

Source: Superfund's Standard Default Exposure Factors for the Central Tendency and Reasonable Maximum Exposure (USEPA, 1993).

CT = Central Tendency
RME = Upper Bound Exposure
(a) = Lower of the 95% upper confidence limit of the mean or the maximum detected value.
(b) = Higher of the 95% upper confidence limit of the mean or the maximum detected value.
(c) = Entire Body. CT = Mean values, RME = Maximum values.
(d) = Bureau of Labor Statistics (USEPA, 1990).
(e) = Best Professional Judgment: Assumption of a 7 Minute Shower.
(f) = Best Professional Judgment: Assumption of a 12 Minute Shower.

TABLE 6.30

EXPOSURE PARAMETERS AND INTAKE ALGORITHM FOR FUTURE SITE WORKER EXPOSURE: INHALATION OF GROUNDWATER WHILE SHOWERING

RADFORD ARMY AMMUNITION PLANT RADFORD, VIRGINIA

$$\text{Intake (mg/kg-day)} = \frac{C \times IR \times ET \times EF \times ED \times CF}{BW \times AT}$$

Parameter		CT	RME
C =	Chemical Concentration in Water (mg/L)	(a)	(b)
IR =	Inhalation Rate (m^3/hr)	1.4	2
CF =	Conversion Factor (L/m^3)	1	1
ET =	Exposure Time (hrs/day)	0.117(c)	0.2(d)
EF =	Exposure Frequency (days/year)	125	250
ED =	Exposure Duration (years)	5(e)	25
BW =	Body Weight (kg)	70	70
AT =	Averaging Time (days)		
	Noncarcinogenic	1,825	9,125
	Carcinogenic	25,550	25,550

Source: Superfund's Standard Default Exposure Factors for the Central Tendency and Reasonable Maximum Exposure (USEPA, 1993).

CT = Central Tendency
RME = Reasonable Maximum Exposure
(a) = Chemical concentration in air is based on the Andelman Shower Model.
(b) = Higher of the 95% upper confidence limit of the mean or the maximum detected value.
(c) = Best Professional Judgment: Assumption of a 7 Minute Shower
(d) = Best Professional Judgment: Assumption of a 12 Minute Shower
(e) = Bureau of Labor Statistics (USEPA, 1990).

TABLE 6.31

EXPOSURE PARAMETERS AND INTAKE ALGORITHM FOR CURRENT CONSTRUCTION WORKER EXPOSURE: SURFACE/SUBSURFACE SOIL INGESTION

RADFORD ARMY AMMUNITION PLANT RADFORD, VIRGINIA

$$\text{Intake (mg/kg-day)} = \frac{C \times IR \times EF \times ED \times CF \times FI}{BW \times AT}$$

Parameter		CT	RME
C	= Chemical Concentration in Soil (mg/kg)	(a)	(b)
IR	= Ingestion Rate (mg/day)	100	480
EF	= Exposure Frequency (days/year)	125	250
ED	= Exposure Duration (years)	0.5(c)	2(c)
CF	= Conversion Factor (kg/mg)	10^{-6}	10^{-6}
FI	= Fraction Ingested (unitless)	1	1
BW	= Body Weight (kg)	70	70
AT	= Averaging Time (days)		
	Noncarcinogenic	182.5	730
	Carcinogenic	25,550	25,550

Source: Superfund's Standard Default Exposure Factors for the Central Tendency and Reasonable Maximum Exposure (USEPA, 1993).

CT = Central Tendency
RME = Reasonable Maximum Exposure
(a) = Lower of the 95% upper confidence limit of the mean or the maximum detected value.
(b) = Higher of the 95% upper confidence limit of the mean or the maximum detected value.
(c) = Best professional judgment.

TABLE 6.32

EXPOSURE PARAMETERS AND INTAKE ALGORITHM FOR CURRENT CONSTRUCTION WORKER EXPOSURE: SURFACE/SUBSURFACE SOIL DERMAL CONTACT

RADFORD ARMY AMMUNITION PLANT RADFORD, VIRGINIA

$$\text{Intake (mg/kg-day)} = \frac{C \times SA \times AF \times EF \times ED \times CF}{BW \times AT}$$

Parameter		CT	R
C =	Chemical Concentration in Soil (mg/kg)	(a)	(b)
SA =	Skin Area (cm2/event) (c)	3,160	4,100
AF =	Skin Adherence Factor (mg/cm2)	1	1
EF =	Exposure Frequency (days/year)	125	250
ED =	Exposure Duration (years)	0.5(d)	2(d)
CF =	Conversion Factor (kg/mg)	10^{-6}	10^{-6}
BW =	Body Weight (kg)	70	70
AT =	Averaging Time (days)		
	Noncarcinogenic	182.5	730
	Carcinogenic	25,550	25,550

Source: Superfund's Standard Default Exposure Factors for the Central Tendency and Reasonable Maximum Exposure (USEPA, 1993).

CT = Central Tendency
RME = Reasonable Maximum Exposure
(a) = Lower of the 95% upper confidence limit of the mean or the maximum detected value.
(b) = Higher of the 95% upper confidence limit of the mean or the maximum detected value.
(c) = Head, forearms and hands: CT = Mean values and Upper Bound = Maximum values.
(d) = Best professional judgment.

TABLE 6.33

EXPOSURE PARAMETERS AND INTAKE ALGORITHM FOR CURRENT CONSTRUCTION WORKER EXPOSURE: INHALATION OF SURFACE/SUBSURFACE SOIL VOLATILES AND PARTICULATES

RADFORD ARMY AMMUNITION PLANT
RADFORD, VIRGINIA

$$\text{Intake (mg/kg-day)} = \frac{C \times IR \times EF \times ED \times [1/PEF \text{ or } 1/VF]}{BW \times AT}$$

Parameter	CT	RME
C = Chemical Concentration in Soil (mg/kg)	(a)	(b)
IR = Inhalation Rate (m^3/hour)	2.0	3.5
ET = Exposure Time (hours/day)	8	8
EF = Exposure Frequency (days/year)	125	250
ED = Exposure Duration (years)	0.5(c)	2(c)
PEF = Particulate Emission Factor (kg/m^3)	site specific	site specific
VF = Volatilization Factor (kg/m^3)	chemical specific	chemical specific
BW = Body Weight (kg)	70	70
AT = Averaging Time (days)		
Noncarcinogenic	182.5	730
Carcinogenic	25,550	25,550

Source: Superfund's Standard Default Exposure Factors for the Central Tendency and Reasonable Maximum Exposure (USEPA, 1993).

CT = Central Tendency
RME = Reasonable Maximum Exposure
(a) = Lower of the 95% upper confidence limit of the mean or the maximum detected value.
(b) = Higher of the 95% upper confidence limit of the mean or the maximum detected value.
(c) = Best professional judgment.

TABLE 6.34

EXPOSURE PARAMETERS AND INTAKE ALGORITHM FOR CURRENT CONSTRUCTION WORKER EXPOSURE: INGESTION OF SURFACE WATER

RADFORD ARMY AMMUNITION PLANT RADFORD, VIRGINIA

$$\text{Intake (mg/kg-day)} = \frac{C \times IR \times EF \times ED \times CF}{BW \times AT}$$

Parameter		CT	RME
C =	Chemical Concentration in Water (mg/L)	(a)	(b)
IR =	Ingestion Rate (L/day)	0.05(c)	0.05(c)
CF =	Conversion Factor (L/L)	1	1
EF =	Exposure Frequency (days/year)	125	250
ED =	Exposure Duration (years)	0.5(c)	2(c)
BW =	Body Weight (kg)	70	70
AT =	Averaging Time (days)		
	Noncarcinogenic	182.5	730
	Carcinogenic	25,550	25,550

Source: Superfund's Standard Default Exposure Factors for the Central Tendency and Reasonable Maximum Exposure (USEPA, 1993).

CT = Central Tendency.
RME = Reasonable Maximum Exposure.
(a) = Lower of the 95% upper confidence limit of the mean or the maximum detected value.
(b) = Higher of the 95% upper confidence limit of the mean or the maximum detected value.
(c) = Best professional judgment.

TABLE 6.35

EXPOSURE PARAMETERS AND INTAKE ALGORITHM FOR CURRENT CONSTRUCTION WORKER EXPOSURE: DERMAL CONTACT WITH SURFACE WATER

RADFORD ARMY AMMUNITION PLANT RADFORD, VIRGINIA

$$\text{Intake (mg/kg-day)} = \frac{C \times SA \times EF \times PC \times ED \times ET \times CF}{BW \times AT}$$

Parameter		CT	RME
C	= Chemical Concentration in Water (mg/L)	(a)	(b)
SA	= Skin Surface Area (cm^2) (c)	3,160	4,100
CF	= Conversion Factor (L/cm^3)	0.001	0.001
EF	= Exposure Frequency (days/year)	125	250
PC	= Permeability Constant (cm/hr)	chemical -specific	chemical-specific
ED	= Exposure Duration (years)	0.5(d)	2(d)
ET	= Exposure Time (hrs/day)	0.15(e)	0.15(e)
BW	= Body Weight (kg)	70	70
AT	= Averaging Time (days)		
	Noncarcinogenic	182.5	730
	Carcinogenic	25,550	25,550

Source: Superfund's Standard Default Exposure Factors for the Central Tendency and Reasonable Maximum Exposure (1993).

CT = Central Tendency
RME = Reasonable Maximum Exposure
(a) = Lower of the 95% upper confidence limit of the mean or the maximum detected value.
(b) = Higher of the 95% upper confidence limit of the mean or the maximum detected value.
(c) = Hands, Face Forearms. CT = Mean values and Upper Bound = Maximum values.
(d) = Best Professional Judgment.
(e) = Best Professional Judgment.

6.5.1.4 Determination of Exposure Point Concentration

6.5.1.4.1. The exposure point concentrations are calculated as the 95 percent upper confidence limit on the arithmetic mean of the analytical results for the representative analytes (USEPA, 1989c). There are two exceptions to this guidance. When a contaminant is detected in only one sample or if only one sample was collected for a certain medium, the single concentration is reported as the exposure point concentration. The second exception occurs when the 95 percent confidence limit exceeds the maximum detected value for a group of samples. In this case, the maximum detected concentration is considered to be the RME and is used as the exposure point concentration.

6.5.1.4.2. The 95% upper confidence limit was calculated per supplemental guidance to RAGS (USEPA, 1992c) using the following equation:

$$95\%\ \text{UCL} = e^{(x + 0.5s^2 + sH\,(n-1)^{0.5})}$$

where:

UCL	=	upper confidence limit;
e	=	constant (base of the natural log equal to approximately 2.718);
x	=	mean of the transformed data;
s	=	standard deviation of the transformed data;
H	=	H-statistic from Table A12 of USEPA (1992c); and
n	=	sample size.

6.5.2 Toxicity Assessment

6.5.2.0.1. The toxicity assessment evaluates the available evidence regarding the potential for particular contaminants to cause adverse effects in exposed individuals and provides, where possible, an estimate of the relationship between the extent of exposure to a contaminant and the increased likelihood and/or severity of adverse effects. Toxicity information considered in this assessment includes the reference dose (RfD), which is used to evaluate non-carcinogenic effects and the slope factor (SF), which is used to evaluate carcinogenic potential.

6.5.2.0.2. The values used in the toxicity assessment are found in the given hierarchy of sources:

1) DTSC guidance through either personal or written communication on cancer potency slope factors;
2) USEPA's Integrated Risk Information System (USEPA, 1995a); and
3) The most current edition of USEPA's Health Effects Assessment Summary Tables (HEAST) (USEPA, 1995b);

6.5.2.0.3. Determining toxicity values for some classes of chemicals can be complicated and is beyond the scope of the preliminary screening. When slope factors and unit risks are not available for all potentially carcinogenic members of a chemical class, toxicity values may be calculated using toxicity equivalency factors (TEFs). These are values that compare the carcinogenic potential of a given chemical in a class to the carcinogenic potential of a chemical in the class that has a verified slope factor and/or unit risk. USEPA has provided TEFs for polyaromatic hydrocarbons (PAHs) (USEPA, 1993) as follows:

TEF VALUES

PAH	TEF
Benzo(a)pyrene	1.0
Benzo(a)anthracene	0.1
Benzo(b)fluoroanthene	0.1
Benzo(k)fluoroanthene	0.01
Chrysene	0.001

6.5.2.0.4. To calculate a slope factor for a given PAH, the appropriate TEF value is multiplied by the slope factor for benzo(a)pyrene. Using the TEF approach, carcinogenic risks resulting from exposure to all carcinogenic PAHs can be quantified.

6.5.2.1 Health Criteria for Non-Carcinogenic Effects

6.5.2.1.1. For chemicals that exhibit non-carcinogenic (e.g., systemic) effects, authorities consider organisms to have repair and detoxification capabilities that must be exceeded by some critical concentration (threshold) before the health effect is manifested. This threshold view holds that a range of exposures from slightly above zero to some finite value can be tolerated by the organism with no appreciable risk of adverse effects.

6.5.2.1.2. Health criteria for chemicals exhibiting non-carcinogenic effects for use in risk assessment are generally developed using USEPA RfDs developed by the Reference Dose/Reference Concentration (RfD/RfC) Work Group and included in the IRIS (USEPA, 1995a). In general, the RfD is an estimate of an average daily exposure to an individual (including sensitive individuals) below which there will not be an appreciable risk of adverse health effects. The RfD accounts for uncertainty factors (e.g., to adjust from animals to humans and to protect sensitive subpopulations) which ensure that it is unlikely to underestimate the potential for adverse non-carcinogenic effects to occur. The purpose of the RfD is to provide a bench mark against which the sum of other doses (i.e., those projected from human exposure to various environmental conditions) might be compared. Doses that are significantly higher than the RfD may indicate that an inadequate margin of safety could exist for exposure to that substance and an adverse health effect could occur. A summary of non-carcinogenic chemical-specific toxicity values is presented in Table 6.36.

6.5.2.1.3. The potential chemicals of concern may affect different target organs in the body. Under RAGS guidance, dose additivity is assumed which implies the same toxic endpoint or target organ.

6.5.2.2 Health Criteria for Carcinogenic Effects

6.5.2.2.1. For chemicals that exhibit carcinogenic effects, most authorities recognize that one or more molecular events can evoke changes in a single cell or a small number of cells that can lead to tumor formation. This is the non-threshold theory of carcinogenesis purporting that any level of exposure to a carcinogen can result in some finite possibility of generating the disease. Generally, regulatory agencies assume the non-threshold hypothesis for carcinogens in the absence of information concerning the mechanisms of action for the chemical.

Table 6.36
Chemical Specific Toxicity Values
Noncarcinogenic Effects (1)
Radford Army Ammunition Plant

CAS No.	Chemical	Oral RfD (mg/kg-day)	RfD Conf. (2)	RfD Critical Effect/Species	Oral Absorption Factor (3)	Dermal RfD (mg/kg-day) (4)	Inhalation RfC (mg/m^3)	RfC Conf. (2)	RfC Critical Effect/Species
	Volatiles								
56-23-5	Carbon Tetrachloride	7.00E-04	Med	Liver effects/ rats	0.85	5.95E-04	NR	-	-
67-66-3	Chloroform	1.00E-02	Med	Fatty cysts in liver/dogs	1.00	1.00E-02	NR	-	-
107-06-2	1,1-Dichloroethane	NR	NR	-	0.90	NA	NR	-	-
75-35-4	1,1-Dichloroethene	9.00E-03	Med	Liver lesions/rats	0.90	8.10E-03	NR	-	-
75-09-2	Methylene Chloride	6.00E-02	Med	Liver toxicity/rats	0.98	5.88E-02	3.00E+00 *	NR	Liver toxicity/rats
98-95-3	Nitrobenzene	5.00E-04	Low	Liver lesions/rats	0.90 #	4.50E-04	NR	-	-
127-18-4	Tetrachloroethene	1.00E-02	Med	Liver tox/mice; weight gain/rats	0.90	9.00E-03	NR	-	-
71-55-6	1,1,1-Trichloroethane	NR	NR	-	0.90 #	NA	NR	-	-
79-01-6	Trichloroethene	NR	NR	-	0.90	NA	NR	-	-
	Semivolatiles								
56-55-3	Benzo(a)anthracene	3.00E-01	Low	No observed effects/mice	0.20 #	6.00E-02	NR	-	-
205-99-2	Benzo(b)fluoranthene	NR	NR	-	0.20 #	NA	NR	-	-
191-24-2	Benzo(g,h,i)perylene	NR	NR	-	0.20 #	NA	NR	-	-
207-08-9	Benzo(k)fluoranthene	NR	NR	-	0.20 #	NA	NR	-	-
117-81-7	Bis(2-ethylhexyl)phthalate	2.00E-02	Med	Increased liver weight/guinea pigs	0.50	1.00E-02	NR	-	-
218-01-9	Chrysene	NR	NR	-	0.60	NA	NR	-	-
84-74-2	Di-n-butylphthalate	1.00E-01	Low	Increased mortality/rats	0.90	9.00E-02	NR	-	-
534-52-1	4,6-dinitro-2-cresol	NR	NR	-	NR	NA	NR	-	-
84-66-2	Diethylphthalate	8.00E-01	Low	Weight, growth decrease/rats	0.50 #	4.00E-01	NR	-	-
131-11-3	Dimethylphthalate	1.00E+01 *	NR	Kidney effects/rats	0.50 #	5.00E+00	NR	-	-
206-44-0	Fluoranthene	4.00E-02	Low	Liver, kidney, blood	0.20 #	8.00E-03	NR	-	-
86-30-6	N-Nitrosodiphenylamine	NR	NR	-	0.20 #	NA	NR	-	-
85-01-8	Phenanthrene	NR	NR	-	0.20 #	NA	NR	-	-
129-00-0	Pyrene	3.00E-02	Low	Kidney effects/mice	0.20 #	6.00E-03	NR	-	-
	Inorganics								
7440-36-0	Antimony	4.00E-04	Low	Longevity, blood effects/rats	0.01	4.00E-06	NR	-	-
7440-38-2	Arsenic	3.00E-04	Med	Skin lesions/humans	0.01	2.40E-04	NR	-	-
7440-39-3	Barium	7.00E-02	Med	Increased blood pressure/humans	0.05	3.50E-03	5.00E-04 *	NR	Fetotoxicity/rats
7440-41-7	Beryllium	5.00E-03	Low	Heart, kidney, spleen effects/ rats	0.01 #	5.00E-05	NR	-	-
7440-43-9	Cadmium	5.00E-04 (5)	High	Significant proteinuria/humans	0.02	1.00E-05	NR	-	-
7440-47-3	Chromium III	5.00E-03	Low	No observed effects/rats	0.02	1.00E-04	NR	-	-
7439-92-1	Lead	NR	NR	-	0.15	NA	NR	-	-
7439-97-6	Mercury	3.00E-04 *	NR	Kidney effects/rats	0.01	3.00E-06	3.00E-04 *	NR	Neurotoxicity/humans
7440-02-0	Nickel	2.00E-02	Med	Decreased body and organ wt/rats	0.04	8.00E-04	NR	-	-
7782-49-2	Selenium	5.00E-03	High	Reproductive effects/ mice	0.90	4.50E-03	NR	-	-
7440-22-4	Silver	5.00E-03	Low	Argyria/humans	0.20	1.00E-03	NR	-	-
	Explosives								
2691-41-0	HMX	5.00E-02	Low	Liver effects/ mice	0.20 #	1.00E-02	NR	-	-
121-14-2	2,4-Dinitrotoluene	2.00E-03	High	-	0.20 #	4.00E-04	NR	-	-
121-82-4	RDX	3.00E-03	High	Decreased body weight/ rats	0.20 #	6.00E-04	NR	-	-
118-96-7	2,4,6-Trinitrotoluene	5.00E-04	Med	Liver effects/ mice	0.20 #	1.00E-04	NR	-	-

(1) From IRIS (USEPA, 1994a). When IRIS values were unavailable, HEAST (USEPA, 1994b) was used. An asterisk (*) indicates that values taken from HEAST.
A double asterisk (**) indicates that value from USEPA (1994c - personal communication with the Superfund Technical Support Center).
RfD = reference dose, NR = not reported, UR = under review, NV = nonverifiable, NA = not applicable
A dash ("-") indicates that this item is not applicable, or that there is no entry in either IRIS or HEAST.

(2) USEPA-assigned level of confidence in toxicity value. Med = medium.

(3) The absorption values were cited in the appropriate ATSDR Profiles. The pound sign (#) indicates that the ATSDR Profiles were not available and default values were used as follows: 0.9 for volatiles, 0.2 for semi-volatiles, pesticides, wet chemistry analytes and explosives, 0.5 for phthalates 0.01 for metals and 1.0 for 1,3-dichlorobenzene (by analogy to 1,4-dichlorobenzene).

(4) Dermal-RfD = Oral-RfD x oral absorption factor.

(5) Two RfD values are available for cadmium and the most conservative is presented.

6.5.2.2.2. USEPA's Carcinogen Risk Assessment Verification Endeavor (CRAVE) has developed slope factors and unit risks (i.e., dose-response values) for estimating excess lifetime cancer risks associated with various levels of lifetime exposure to potential human carcinogens. The carcinogenic slope factors can be used to estimate the lifetime excess incremental cancer risk associated with exposure to a potential carcinogen. Risks estimated using slope factors are considered unlikely to underestimate actual risks, but they may overestimate actual risks. Excess lifetime cancer risks are generally expressed in scientific notation and are probabilities. For example, an excess risk of 1×10^{-6} (one in one million) represents the added probability of an individual developing cancer over a lifetime as a result of exposure to the specific carcinogenic chemical under the exposure conditions used for the analysis. USEPA has suggested developing remedial alternatives for cleanup of Superfund sites using a target total excess lifetime cancer risk ranging from 10^{-4} (one in ten thousand) to 10^{-6} (one in one million) (USEPA, 1990). A summary of carcinogenic chemical-specific toxicity values is presented in Table 6.37.

6.5.2.2.3. In addition, there are varying degrees of confidence in the weight-of-evidence for carcinogenicity of a given chemical. The USEPA's system involves characterizing the overall weight-of-evidence for a chemical's carcinogenicity based on the availability of animal, human, and other supportive data. The weight-of-evidence classification is an attempt to determine the likelihood that the agent is a human carcinogen, and thus qualitatively affects the estimation of potential health risks. Three major factors are considered in characterizing the overall weight-of-evidence for carcinogenicity: (1) the quality of evidence from human studies; (2) the quality of evidence from animal studies, which are combined into a characterization of overall weight of evidence for human carcinogenicity; and (3) other supportive information that is assessed to determine whether the overall weight-of-evidence should be modified. Uncertainty values are not associated with carcinogenic toxicity values because the uncertainty is reflected by the category to which the chemical is assigned. USEPA's final classification of the overall weight-of-evidence includes the following five categories:

Table 6.37
Chemical Specific Toxicity Values
Carcinogenic Effects (1)
Radford Army Ammunition Plant

CAS No.	Chemical	CAG Group (2)	Oral Slope Factor $(mg/kg\text{-}day)^{-1}$	Oral Slope Factor Target Organ (Tumor Type)/Species	Oral Absorption Factor (3)	Dermal Slope Factor $(mg/kg\text{-}day)^{-1}$ (4)	Inhalation Unit Risk $(mg/kg\text{-}day)^{-1}$	Inhalation Unit Risk Target Organ (Tumor Type)/Species
	Volatiles							
56-23-5	Carbon Tetrachloride	B2	1.30E-01	Liver (Adenoma)/Rats	0.90	1.53E-01	1.50E-05	-
67-66-3	Chloroform	B2	3.10E-02 **	-	1.00	3.10E-02	5.43E-06 **	-
107-06-2	1,1-Dichloroethane	B1	7.00E-02 **	-	0.90	7.78E-02	2.00E-05 **	-
75-35-4	1,1-Dichloroethene	C	6.00E-01	Adrenal gland (tumors)/ Rats	0.90	6.67E-01	5.14E-05	Kidney (adenocarcinoma): mice
75-09-2	Methylene Chloride	B2	1.40E-02 **	-	0.98	1.43E-02	1.00E-06 **	-
98-95-3	Nitrobenzene	D	NR	-	0.90	NA	NR	-
127-18-4	Tetrachloroethene	NR	5.10E-02 **	-	0.90	5.67E-02	1.46E-05 **	-
71-55-6	1,1,1-Trichloroethane	D	NR	-	0.90 #	NA	NR	-
79-01-6	Trichloroethene	NR	1.50E-02 **	-	0.90	1.67E-02	2.86E-06 **	-
	Semivolatiles							
56-55-3	Benzo(a)anthracene	B2	7.30E-01 (5)	Forestomach (carcinomas)/ Mice	0.20 #	3.65E+00	NR	-
205-99-2	Benzo(b)fluoranthene	B2	7.30E-01	Lung (adenoma)/ Rats	0.20 #	3.65E+00	2.38E-04	-
191-24-2	Benzo(g,h,i)perylene	D	NR	Lung (adenoma)/ Mice	0.20 #	NA	NR	-
207-08-9	Benzo(k)fluoranthene	B2	7.30E-01	Lung (adenoma)/ Rats	0.20 #	3.65E-01	1.12E-04	-
117-81-7	Bis(2-ethylhexyl) phthalate	B2	8.40E-03 **	Liver (adenoma and carcinoma)/ Mice	0.50	1.68E-02	2.40E-06 **	-
218-01-9	Chrysene	B2	7.30E-03 (5)	Forestomach (carcinomas)/ Mice	0.60	1.22E-02	NR	-
84-74-2	Di-n-butylphthalate	D	NR	-	0.90	NA	NR	-
534-52-1	4,6-dinitro-2-cresol	NR	NR	-	NR	NA	NR	-
84-66-2	Diethylphthalate	NA	NR	-	NA	NA	NR	-
131-11-3	Dimethylphthalate	D	NR	-	0.50 #	NA	NR	-
206-44-0	Fluoranthene	D	NR	-	0.20 #	NA	NR	-
86-30-6	N-Nitrosodiphenylamine	B2	4.90E-03	Urinary bladder (carcinoma)/ Rats	0.20 #	2.45E-02	NR	-
85-01-8	Phenanthrene	D	NR	-	0.20 #	NA	NR	-
129-00-0	Pyrene	D	NR	-	0.20 #	NA	NR	-
	Inorganics							
7440-36-0	Antimony	NR	NR	-	0.01	NA	NR	-
7440-38-2	Arsenic	A	1.80E+00	Skin(carcinoma)/Humans	0.01	2.19E+00	1.23E-06	Lung (carcinoma)/humans
7440-39-3	Barium	NR	NR	-	0.05	NA	NR	-
7440-41-7	Beryllium	B2	4.30E+00	Leukemia/ Rats	0.01 #	4.30E+02	1.61E-03	-
7440-43-9	Cadmium	B1	NR	-	0.02	NA	4.29E-03 **	-
7440-47-3	Chromium III	A	4.20E-01 **	-	0.02	2.10E+01	1.46E-01 **	-
7439-92-1	Lead	B2	NR	-	0.15	NA	NR	-
7439-97-6	Mercury	D	NR	-	0.01	NA	NR	-
7440-02-0	Nickel	NR	NR	-	0.04	NA	2.60E-04 **	-
7782-49-2	Selenium	D	NR	-	0.01 #	NA	NR	-
7440-22-4	Silver	D	NR	-	0.20	NA	NR	-
	Explosives							
2691-41-0	HMX	D	NR	-	0.20 #	NA	NR	-
121-14-2	2,4-Dinitrotoluene	NR	NR	-	0.20 #	NA	NR	-
121-82-4	RDX	C	3.00E-03	Liver (adenoma)/ Mice	0.20 #	5.50E-01	NR	-
118-96-7	2,4,6-Trinitrotoluene	C	3.00E-02	Urinary Bladder (papilloma)/ Mice	0.20 #	1.50E-01	NR	-

(1) From IRIS (USEPA, 1994a). When IRIS values were unavailable, HEAST (USEPA, 1994b) was used. An asterisk (*) indicates that values taken from HEAST.
A double asterisk (**) indicates that value from USEPA (1992 - personal communication with the Superfund Technical Support Center).
NR = not reported, UR = under review
A dash ("-") indicates that this item is not applicable, or that there is no entry in either IRIS or HEAST.
(2) CAG = USEPA Carcinogen Assessment Group (see text).
(3) The absorption values were cited in the appropriate ATSDR Profiles. The pound sign (#) indicates that the ATSDR Profiles were not available and default values were used as follows: 0.9 for volatiles, 0.2 for semi-volatiles, pesticides, wet chemistry analytes and explosives, 0.5 for phthalates 0.01 for metals and 1.0 for 1,3-dichlorobenzene (by analogy to 1,4-dichlorobenzene).
(4) Dermal-SF = Oral-SF/oral absorption factor.
(5) The slope factor is for the mixture of 2,4/2,6-dinitrotoluene.
(6) The slope factor for arsenic was derived from an oral unit risk of 5E-05 (L/ug).

- **Group A - Human Carcinogen** - This category indicates that there is sufficient evidence from epidemiological studies to support a causal association between an agent and cancer.
-
- **Group B - Probable Human Carcinogen** - This category indicates that there is at least limited evidence from epidemiological studies of carcinogenicity to humans (Group B1) or that, in the absence of adequate data on humans, there is sufficient evidence of carcinogenicity in animals (Group B2).
- **Group C - Possible Human Carcinogen** - This category indicates that there is limited evidence of carcinogenicity in animals in the absence of data on humans.
- **Group D - Not Classified** - This category indicates that the evidence for carcinogenicity in animals is inadequate.
- **Group E - No Evidence of Carcinogenicity to Humans** - This category indicates that there is no evidence for carcinogenicity in at least two adequate animal test in different species, or in both epidemiological and animal studies.

6.5.2.2.4. Slope factors and unit risks are developed by the USEPA based on epidemiological or animal bioassay data for a specific route of exposure (oral or inhalation). The slope factor is the upper 95th percentile confidence limit of the slope of the dose response curve and is expressed as $(mg/kg\text{-}day)^{-1}$. The dose response relationship is linear only in the low dose region and therefore the slope factor is more accurate in this region. There is a high degree of uncertainty when extrapolating from high dose to low dose and from animal doses to human doses. For some chemicals, sufficient data are available to develop route-specific slope factors for inhalation and ingestion.

6.5.2.3 Identified Carcinogens in Chemical of Concern List

6.5.2.3.1. Arsenic and chromium III have been classified as human carcinogens by USEPA and have been assigned a carcinogenicity weight-of-evidence category of Group A.

6.5.2.3.2. 1,1-dichloroethane and cadmium have been classified as probable human carcinogens by USEPA and have been assigned a carcinogenicity weight-of-evidence category of Group B1.

6.5.2.3.3. Carbon tetrachloride, chloroform, methylene chloride, benzo(a)anthracene, benzo(b)fluoranthene, benzo(k)fluoranthene, bis(2-ethylhexyl)phthalate, chrysene, N-nitrosodiphenylamine, beryllium and lead have been classified as a probable human carcinogens by USEPA, and have also been assigned a carcinogenicity weight-of-evidence category of Group B2.

6.5.2.3.4. The USEPA has placed lead in the weight-of-evidence group B2, indicating that it is a probable human carcinogen. There is sufficient animal evidence that lead is carcinogenic, however the human evidence is inadequate. Quantifying lead's cancer risk involves many uncertainties, some of which may be unique to lead. Age, health, nutritional state, body burden and exposure duration influence the absorption, release and excretion of lead. In addition, current knowledge of lead pharmacokinetics indicates that an estimate derived by existing standard procedures would not truly describe the potential risk. Therefore, a numerical estimate is not used to describe carcinogenic effects of lead.

6.5.2.3.5. 1,1-Dichloroethylene, butylbenzyl-phthalate, RDX and 2,4,6-trinitrotoluene have been classified as possible human carcinogens by USEPA and have been assigned a carcinogenicity weight-of-evidence category of Group C.

6.5.2.4 Inhalation Exposure

6.5.2.4.1 **Conversion of RfCs and IURs** - For inhalation pathways, reference concentrations (RfCs) and inhalation unit risks (IURs) should be used when available to calculate inhalation reference doses (IRfDs) and inhalation slope factors (ISFs) to assess risks via inhalation.

RfCs should be converted to the reference dose using the following equation:

$$\text{IRfD (mg/kg-day)} = \text{RfC (mg/m}^3\text{)} \times 20\ \text{m}^3 \text{ per day per } 70\ \text{kg.}$$

Inhalation Unit Risks (IURs) should be converted to ISFs using the following equation:

$$\text{ISFs (kg-day/mg)} = \text{IUR (m}^3\text{/ug)} \times 70\ \text{kg} \times 20\ \text{m}^3 \text{ per day} \times 1000\ \text{ug per mg}$$

6.5.2.4.2 **Determination of Volatility** - Based on the physical characteristics of the detected contaminants (Table 6.14), a determination was made concerning the volatility of each compound. Chemicals having a Henry's Law constant greater than 10^{-5} and a molecular weight greater than 200 were considered to be volatile (USEPA, 1991). Chemicals not meeting these criteria were considered to be non-volatile. Chemicals without information concerning either the Henry's Law Constant or the molecular weight were not evaluated for the inhalation pathway. It should be noted that each chemical is represented only once as either a volatile or particulate (nonvolatile).

6.5.2.4.3 **Calculation of the PEF** - The particulate emission factor (PEF) relates the soil contaminant concentration to the air concentration of respirable particles due to fugitive dust emissions. This relationship is applicable to typical hazardous waste sites and is dependent on the assumption that the site will provide a relatively continuous and constant potential for emission over an extended period of time. Particulate emissions are generated by wind erosion and are dependent on the type of surface material and the vegetative cover. PEF values are generated using the following equation:

$$PEF = (LS \times V \times DH \times Cfa \times Cfb) - (A \times RF \times (1-G) \times (UM/UT)^3 \times Fx)$$

where:

PEF = particulate emission factor (m^3/kg)
LS = length of side of contaminated area (site specific, meters)
V = wind speed in mixing zone (2.25 m/sec, default)
DH = diffusion height (2 meters = average human height)
A = area of contamination (site specific, m^2)
RF = respirable fraction (constant = 0.4 g/m^3-hr)
G = fraction of vegetative cover (site specific, unitless)
UT = equivalent threshold value of wind speed at 10 m (12.8 m/sec, default)
UM = mean annual wind speed (6 m/sec - data from Defense Priority Model, 1993)
Fx = constant (0.5, unitless)
Cfa = conversion factor (3,600 sec/hr)
Cfb = conversion factor (1,000 g/kg)

6.5.2.4.4. Certain variables require site specific inputs (i.e. area of contamination and fraction of vegetative cover); where site specific information is not available, default values provided by RAGS (EPA, 1989c) were used. Site specific information used in this calculation includes the length of the contaminated side of the SWMU, the area of contamination, the fraction of vegetative cover, and the mean annual wind speed in this area.

6.5.2.4.5. The length of the contaminated side of each SWMU was measured from scale drawings showing the known and suspected contaminated locations. As a conservative measure, the longest side of each SWMU was used to approximate this distance to account for potential unknown contaminated areas. The area of contamination was also calculated from scale drawings of the study area.

6.5.2.4.6. The fraction of vegetative cover is a qualitative estimate expressed as a percentage for the site. Background information for each SWMU from the RCRA Facility Investigation Work Plan (Engineering Science, 1994a) was used to determine this parameter. The mean annual wind speed for this calculation was determined using meteorological data from the RAAP monitoring station.

6.5.2.4.7 **Calculation of the VF** - A volatilization factor was calculated to arrive at an estimation of soil - to - air volatilization. The volatilization factor is based on a number of site-specific and chemical-specific properties and is calculated as follows:

$$VF = (LS \times V \times DH \times (3.14 \times d \times T)^{0.5})/(A \times 2Dei \times E \times Kas \times CF)$$

where:

VF = volatilization factor (m^3/kg)
LS = length of side of contaminated area (site-specific, meters)
V = wind speed in mixing zone (2.25 m/sec, default)
DH = diffusion height (2 meters = average human height)
$d = (Dei \times E)/(E + Ps)(1 - E)/Kas$
T = the exposure interval (7.9×10^{-8} seconds, default)
A = area of contamination (site specific, m^2)
Dei = the effective diffusivity of the chemical (cm^2/sec)

E = true soil porosity (0.135 used Basewide for silty clay)
Ps = true soil density (2.65 g/cm^3 Basewide for silty clay)
Kas = (H/Kd) x 41 (g soil/cm^3 air)
H = Henry's Law Constant (atm-m^3/mol)
Kd = Koc x OC (cm^3/g)
CF = Conversion factor (0.001 kg/g)
Koc = organic carbon partition coefficient for each chemical (cm^3/g)
OC = fraction of organic carbon (0.2 - default)

6.5.2.4.8 **Volatilization During Showering Indoor Air Model** - Exposure point concentrations for VOCs released from water during showering were modeled on the basis of work conducted by Andelman (1984, 1985a, and 1985b). In the model, the air concentration is determined by a balance between the rate of release from the shower water ant the rate of air exchange between the shower and the rest of the house. The constants occurring in the model have been set to match the observed efficiency of volatilization of trichloroethylene (TCE) in model showers, and to fit the observed shower air concentrations of TCE in several homes with contaminated water where measurements have been made. Scaling to other compounds is accomplished by assuming the rate of volatilization from shower water to air is proportional to the Henry's Law Constant. The time-weighted average concentration of a volatile compound in the shower air over a period of t_s minutes is:

$$C_s = C_{inf} [(1 + (1/Kt_s)) (\exp(-kt_s)-1)] \quad \text{for } t_s > 0$$

where:

C_s = average concentration of a volatile compound in the shower air (mg/m^3) over a duration of t_s (min)
t_s = time in shower (default value 12 min.)
K = rate constant for exponential function, defined below (1/min)
k = F_a/V_b (unitless)
F_a = flow rate of air in shower (2.4 m^3/min, default)
V_b = volume of bathroom (12 m^3, default)
C_{inf} = asymptotic concentration in air (mg/m^3) for shower running longer than 5 min.
$C_{inf} = [(E)(F_w)(C_t/1,000)]F_a$ (mg/m^3)

C_t = concentration in shower water (mg/L)

E = efficiency of release of compounds from water to air, defined below (unitless)

$E = (E_{TCE})(H)(H_{TCE})$

F_w = Flow rate of water in shower (8 L/min, default)

E_{TCE} = efficiency of release of TCE from water to air (0.6, default)

H = Henry's Law Constant (m^3 - atm/mol)

H_{TCE} = Henry's Law Constant for TCE (9.1×10^{-3} m^3 - atm/mol)

6.5.2.4.9. The concentration of VOCs in the water were based on the groundwater concentrations. The concentration of VOCs in the shower air will be modeled for the adult resident.

6.5.2.5 Dermal Exposure

6.5.2.5.1. Currently, USEPA has not identified toxicity reference values for dermal exposure and information is limited for determining uptake of chemicals across intact skin. USEPA RAGS guidance allows for an adjustment of oral toxicity information to quantitatively evaluate potential dermal exposures (USEPA, 1989c). Since most RfDs and slope factors are expressed as the amount of substance administered per unit time and unit body weight, it may be necessary to adjust oral toxicity values from administered doses to absorbed doses. Oral absorption factors are taken from the appropriate Agency for Toxic Substances and Disease Registry (ATSDR) profile; when these profiles are unavailable, default values based on the chemical classification are used.

6.5.2.5.2. Of the nineteen chemicals for which there are no dermal RfDs and slope factors available, only one study has been conducted concerning the dermal effects. The dermal effects of phenanthrene has been studied on laboratory animals. While the results are inconclusive, there are indications that chronic exposures will result in adverse effects. Chronic dermal exposures to these chemicals have not been examined for human subjects.

6.5.3 Risk Characterization

6.5.3.0.1. To characterize risk, toxicity and exposure assessments are summarized and integrated into quantitative and qualitative expressions of risk. To characterize potential non-

carcinogenic effects, comparisons are made between projected intakes of substances and reference dose values. To characterize potential carcinogenic effects, probabilities that an individual will develop cancer over a lifetime of exposure are estimated for projected intakes and chemical-specific slope factors.

6.5.3.1 Non-Carcinogenic Effects

6.5.3.1.1. The potential for non-carcinogenic effects is evaluated by comparing an exposure level over a specified time period (e.g., lifetime) with an RfD derived for a similar exposure period. This ratio of exposure to toxicity is called a hazard quotient according to the following equation:

$$\text{Noncancer Hazard Quotient} = E/RfD$$

Where:

E = Exposure level or intake, and
RfD = Reference dose.

6.5.3.1.2. The noncancer hazard quotient assumes that there is a level of exposure below which it is unlikely that even sensitive individuals will experience adverse health effects (i.e., an RfD). If the exposure level (E) exceeds the threshold (i.e., if E/RfD exceeds unity), there may be concern for potential noncancer effects.

6.5.3.1.3. To assess the overall potential for non-carcinogenic effects posed by more than one chemical, a hazard index (HI) approach has been developed by USEPA. This approach assumes that simultaneous sub-threshold exposures to several chemicals could result in an adverse health effect. It also assumes that the magnitude of the adverse effect will be proportional to the sum of the ratios of the subthreshold exposures. This is expressed as:

$$HI = E_1\backslash RfD_1, + E_2/RfD_2 + \ldots + E_i/RfD_i$$
$$\text{or } HI = HQ_1 + HQ_2 + \ldots + HQ_i$$

Where:

E_i = the exposure level or intake of the i^{th} toxicant, and
RfD_i = reference dose for the i^{th} toxicant
HQ_i = hazard quotient for the i^{th} toxicant.

6.5.3.1.4. Any single chemical with an exposure level greater than the toxicity threshold will cause the HI to exceed unity. For multiple chemical exposures, the HI can also exceed unity even if no single chemical exposure exceeds its RfD. The assumption of dose additivity reflected in the HI is best applied to compounds that induce the same effects by the same mechanisms. Applying the HI to cases where the known compounds do not induce the same effect may overestimate the potential for effects. To assess the overall potential for non-carcinogenic effects posed by several exposure pathways, the total HI for chronic exposure is the sum of the HIs for each pathway.

6.5.3.2 Carcinogenic Effects

6.5.3.2.1. Carcinogenic risks are estimated as the incremental excess probability of an individual developing cancer over a lifetime as a result of exposure to the potential carcinogen (i.e., excess individual lifetime cancer risk). The slope factor converts estimated daily intakes (averaged over a lifetime of exposure) directly to incremental risk of an individual developing cancer. In general, it can be assumed that the dose-response relationship will be linear in the low-dose portion of the multistage model dose-response curve. Under this assumption, the slope factor is a constant and risk will be directly related to intake. Thus, the following linear low-dose equation was used in this assessment:

$$Risk = CDI \times SF$$

Where:

Risk = A unitless probability of an individual developing cancer a result of exposure,
CDI = Chronic Daily Intake averaged over 70 years (mg/kg-day), and
SF = Slope Factor $(mg/kg\text{-}day)^{-1}$.

6.5.3.2.2. Because the slope factor is often an upper 95th-percentile confidence limit of the probability of a response and is based on experimental animal data used in the multistage

model, the carcinogenic risk will generally be an upper-bound estimate. This means that the "true risk" is not likely to exceed the risk estimate derived through this model and is likely to be less than predicted.

6.5.3.2.3. For simultaneous exposure to several carcinogens, USEPA assumes that the risks are additive (USEPA, 1989b). That is to say:

$$Risk_T = Risk_1 + Risk_2 \ldots + Risk_i$$

Where:

$Risk_T$ = Total cancer risk, expressed as a unitless probability, and
$Risk_i$ = Risk estimate for the i^{th} substance.

Addition of the carcinogenic risks is valid when the following assumptions are met:

- doses are low;
- no synergistic or antagonistic interactions occur; and
- similar endpoints are evaluated.

6.5.3.2.4. According to the National Contingency Plan guidance (USEPA, 1990), the acceptable target carcinogenic risk levels are for a lifetime cancer risk range between 10^{-4} to 10^{-6}. This represents a target risk range, and actual risk levels are developed on a site-specific basis.

6.5.3.3 Uncertainty Analysis

6.5.3.3.1. All risk assessments involve the use of assumptions, judgments, and imperfect data to varying degrees. This results in uncertainty in the final estimates of risk. There are several categories of uncertainty associated with risk assessments. One is the initial selection of substances selected for analysis and therefore used to characterize exposures. Uncertainties are inherent in the exposure assessments for individual substances and individual exposures. These uncertainties are usually driven by uncertainty in the chemical monitoring data, but can also be driven by population intake parameters. Another source of uncertainty is the availability of toxicity information for the chemicals detected at

the RAAP. Other sources of uncertainty are inherent in the toxicity values for each substance used to characterize risk. Finally, additional uncertainties are incorporated into the risk assessment when exposures to several substances across multiple pathways are summed and linear additivity is assumed.

6.5.3.3.2. **Uncertainty in Data Collection and Evaluation** - Uncertainties in the data collection/evaluation step of the risk assessment focus on determining whether enough samples were collected to adequately characterize the risk, and if sample analyses were conducted in a qualified manner to maximize the confidence in the results. Because the Work Plans and Quality Assurance Project Plans were developed to collect samples from zones most likely to have been affected by site activities, the samples were collected randomly from areas of suspected contamination. This biased sampling effort may tend to overestimate the risk at certain SWMUs. In addition, the distinction between surface and subsurface soils was based upon differences in soil horizons when inorganic background sample analysis was performed. This may lead to uncertainty in determining differences between surface and subsurface exposure, and may over- or underestimate risk.

6.5.3.3.3. Chemicals that were never detected were eliminated from the assessment. It is possible, but unlikely, that some chemicals were present below the sample quantitation limit (SQL) and not retained in the assessment. Since samples were collected at areas where concentrations were most likely to be high, it is very unlikely that any chemicals were present at a site at health-significant levels and not detected in at least one sample. However, if this did occur, this assumption would underestimate risk.

6.5.3.3.4. If an inorganic chemical was detected above background, it was retained in the risk assessment regardless of how frequently it was detected. All organic chemicals were retained in the risk assessment. To calculate the exposure concentrations, chemicals were assumed to be present in all samples within a media. When the chemical was not detected in a sample, one-half of the SQL was used. Especially for chemicals that were detected in only a few samples, the 95 percent upper confidence interval or maximum value probably greatly overestimates the amount of the chemical present and, consequently, overestimates the risk from the chemical.

6.5.3.3.5. Chromium exists in two oxidation states: trivalent (chromium III) and hexavalent (chromium VI). Each has a screening Risk Based Concentration (RBC) specific to that oxidation state. Sample analysis provided results for total chromium and did not identify oxidation states. However, chromium occurs in nature principally as the trivalent form. Trivalent chromium is the most stable form; hexavalent chromium is a moderately strong oxidizing agent that reacts with organic materials and is reduced to trivalent chromium. In addition, the main source of hexavalent chromium is chromate and dichromate used in the manufacture of chrome steels and alloys or in plating operations. These types of activities did not occur at the RAAP. Therefore, trivalent chromium is the expected oxidation state at the RAAP.

6.5.3.3.6. The data also include a number of data validation flags, as detailed in Subsection 5.2. Qualified data were retained following RAGS guidance. A common qualifier used in risk assessment is the J qualifier. J-qualified data indicates uncertainty in the reported concentration of the chemical, but not in the assigned identity. RAGS guidance (USEPA, 1989) allows for the retention of J-qualified chemical concentrations the same way as positive data without the J qualifier. The uncertainty in the reported chemical concentration can over- or underestimate risk.

6.5.3.3.7. **Uncertainty in Exposure Assessment** - A large part of the risk assessment is estimating risks that are conditional upon the existence of exposure conditions analyzed. If exposure does not occur, no risks are present. Once pathways are identified, exposure point concentrations must be estimated. There is always some doubt as to how well an exposure model approximates the actual conditions receptors will be exposed to at a given site. Key assumptions in estimating exposure point concentrations and exposure assumptions and their potential impact on the assessment are described in the following paragraphs.

6.5.3.3.8. Exposure point concentrations were based on steady state conditions; therefore, future concentrations are assumed to be identical to current concentrations. This assumption may tend to overestimate long-term exposure concentrations because chemical concentrations are likely to decrease over time from natural processes such as dispersion, attenuation, and dilution during migration to potential receptors.

6.5.3.3.9. One of the main areas of uncertainty in exposure assessment is determining land use. At the RAAP, most of the area is industrial and current access is limited to official visitors. As a conservative measure, future land use within RAAP was assumed to be developed for residential use. This may tend to over- or underestimate risks at the RAAP.

6.5.3.3.3.9.1. Another uncertainty in exposure assessment is the particulate emission factor (PEF) used to quantify the generation of fugitive dusts from surface contamination. The PEF calculation is not chemical-specific and therefore, it does not account for the different physical characteristics of the contaminants. In this respect, all chemicals were assumed to have the same behavior when adsorbed to fugitive dust particles. This may tend to over- or underestimate risk. Additionally there is always uncertainty associated with modeled concentrations. Models were used to estimate volatilization from soils, particulate generation and volatilization during showering. Assumptions were made in each of these models that may over- or underestimate risk.

6.5.3.3.3.9.2. **Uncertainty in Toxicity Assessment** - Some uncertainty is inherent in the toxicity values for the duration of exposure assessed. Many of the studies are based on animals and extrapolated to humans, and in some cases, subchronic studies may be used to assess chronic effects. As stated in the toxicity assessment section, several uncertainties apply in these extrapolations. Because slope factors are generally based on the upper limit of the 95th-percentile confidence interval, chemical-specific risks may be overestimated. Reference doses are also chosen conservatively and make use of safety factors.

6.5.3.3.3.9.3. USEPA has not published dermal toxicity values and therefore, adjustments are made to the oral toxicity values in order to quantitatively evaluate risks through dermal exposure. There is also uncertainty associated with the lack of toxicity data and studies for some of the chemicals of concern. These chemicals are unable to be quantitatively assessed in the risk assessment. This lack of data and adjusted oral data may tend to over- or underestimate risk.

6.5.3.3.3.9.4. Risks to construction workers were assessed as though their exposure were chronic or long-term rather than subchronic or short-term. Using a chronic exposure is a conservative assumption and tends to overestimate risks.

6.5.3.3.3.9.5. **Uncertainty In Risk Characterization** - Uncertainties in the toxicity assessment are compounded under the assumption of dose additivity for multiple substance exposure. That assumption ignores possible synergisms and antagonisms among chemicals and assumes similarity in mechanisms of action and metabolism. For noncarcinogens the assumption of dose additivity, established by RAGS guidance and reflected in the HI, is best applied to compounds that induce the same target organ effects by the same mechanisms. Applying the HI to cases where the known compounds do not induce the same effect or where positive synergism between chemicals is apparent may under- or overestimate the potential for effects. Similarly, risks summed for chemicals having various weight-of-evidence classifications as well as different target organs may also tend to overestimate risk.